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Regulatory Impact Analysis of Environmental Standards for Uranium Mill Tailings at Active Sites

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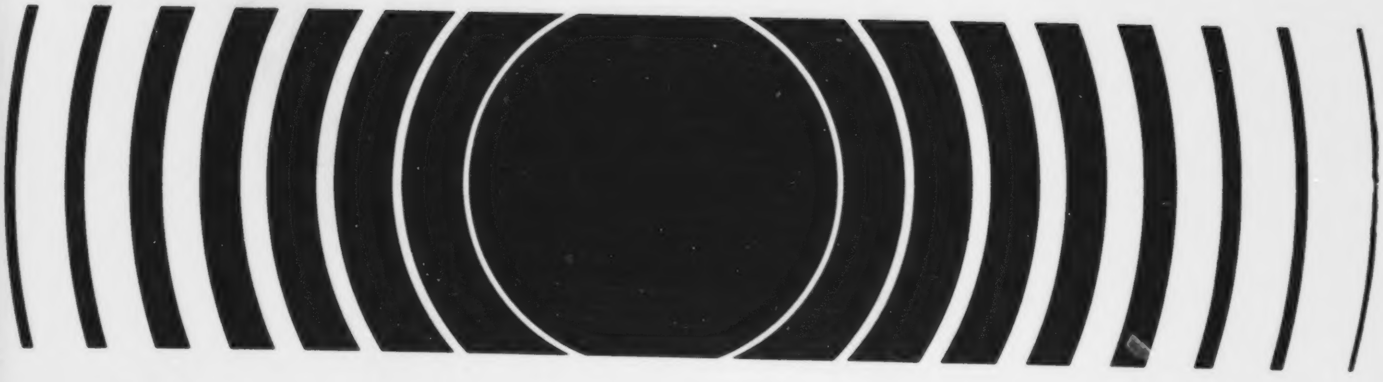

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16. ABSTRACT

The Environmental Protection Agency was directed by Congrss, under PL 95-604, the Uranium Mill Tailings Radiation Control Act of 1978, to set standards of general application that provide protection from the hazards associated with uranium mill tailings. Title I of the Act pertains to tailings at inactive sites for which the Agency has developed standards as part of a separate rulemaking. Title II of the Act requires standards covering the processing and disposal of byproduct materials at mills which are currently licensed by the appropriate regulatory authorities. This Regulatory Impact Analysis (RIA) addresses the standards developed under Ttile II. There are two major parts of the standards for active mills: standards for control of releases from tailings during processing operations and prior to final disposal, and standards for protection of the public after the disposal of tailings. This report presents a detailed analysis of standards for disposal only, since the analysis required for the operations standards is limited because most of the requirements reflected by the operations standards are already in existence through regulations established under the Atomic Energy Act (AEA), the Clean Water Act (CWA), and the Solid Waste Disposal Act (SWDA). Also, the Act directs EPA to develop groundwater protection standards which are consistentwith the standards promulgated under the SWDA, as amended. Consequently, there are very few regulatory alternatives to be considered in the development of standards for control of mill tailings during the operational phase of a mill.

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SUMMARY

Background

The Environmental Protection Agency was directed by Congress, under PL 95-604, the Uranium Mill Tailings Radiation Control Act of 1978, to set standards of general application that provide protection from the hazards associated with uranium mill tailings. Title I of the Act pertains to tailings at inactive sites for which the Agency has developed standards as part of a separate rulemaking. Title II of the Act requires standards covering the processing and disposal of byproduct materials at mills which are currently licensed by the appropriate regulatory authorities. This Regulatory Impact Analysis (RIA) addresses the standards developed under Title II.

There are two major parts of the standards for active mills: standards for control of releases from tailings during processing operations and prior to final disposal, and standards for protection of the public after the disposal of tailings. This report presents a detailed analysis of standards for disposal only, since the analysis required for the operations standards is very limited. The analysis for the operations standards is limited because most of the requirements reflected by the operations standards are already in existence through regulations established under the Atomic Energy Act (AEA), the Clean Water Act (CWA), and the Solid Waste Disposal Act (SWDA). Also, the Act directs EPA to develop groundwater protection standards which are consistent with the standards promulgated under the SWDA, as amended. Consequently, there are very few regulatory alternatives to be considered in the development of standards for control of mill tailings during the operational phase of a mill. For completeness, the operations standards and an explanation of their basis are presented in this report along with the disposal standards. The reader should refer to the Environmental Impact Statement (EIS) which accompanies the RIA for more information on the analysis of the operations standards.

Methodology

The selection of the proposed standards is based primarily on an analysis of the benefits and costs associated with the disposal of uranium mill tailings. This analysis determines what level of control of the hazards is optimal. An economic impact analysis which estimates the economic consequences of incurring such costs was then used to tailor the implementation requirements so as to mimimize these consequences, and to determine that the optimal values for standards could be reasonably imposed.

We performed separate benefit-cost analyses for existing tailings and new tailings piles to reflect differences between past and future practice, both of scale and of control methods. We estimated costs for several tailings disposal methods on the basis of model piles. These methods assume different degrees of earthen cover and surface stabilization as the technique for providing long-term control. In the benefits analysis, the health effects averted by control of radon emanation from tailings piles is the only benefit we can quantify. However, we believe that the most significant benefit is the deterrence of misuse of the tailings by the public. In order to relate the cost estimates to a measure of the overall benefit of a disposal method, we developed an effectiveness index which rates each disposal method according to its effectiveness in providing four specified control classes: prevention of misuse, radon control, prevention of the surface spread of tailings, and groundwater protection. A cost-effectiveness analysis was used to evaluate the average and incremental costs per unit of this effectiveness index for each disposal method. Based on this evaluation of incremental costs, we selected disposal methods which represent an optimal level of control.

Disposal standards were then developed which reflect the level of control that was determined by the cost-effectiveness analysis. Since the standards are generally applicable technical performance and containment standards rather than design standards, they do not specify particular methods of compliance. The determination of implementation requirements for the standards, such as the groundwater protection requirements at existing mills, was based on considerations beyond those addressed in the cost-effectiveness analysis and is discussed in Chapter 6.

Alternative Standards

Table S.1 lists six alternative standards which we have considered for the control of mill tailings after disposal. These alternative standards are stated in terms of a radon emission limit and/or a requirement for longevity of control. We feel that the combination of these two requirements will satisfy the objectives of misuse prevention, radon control, prevention of surface spread of tailings, and groundwater protection. Each of these alternatives will meet the control objectives to a different degree. The alternative standards range from no controls to substantial levels of control which approximate the achievement of basically the same environmental consequences as might occur if the uranium ore had not been mined. Table S.1 summarizes the benefits of each alternative standard through the use of several quantitative and qualitative measures.

Each of these alternative standards assumes a uniform level of control for both existing tailings and new tailings. In this RIA, we have also analyzed requiring different levels of controls for each tailings category. These six cases only are presented here to give some perspective in a simple, yet informative, way on the full range of control levels and their associated benefits and costs. Table S.2 presents the costs of each alternative, as well as the control method assumed for the cost estimation.

Table S.1. Summary of Benefits for Alternative Standards

		Stabilization			Radon Control			Water Protection
						Deaths Avoided[b]		
	Alternative Standards	Chance of Misuse	Misuse Inhibited (y)	Erosion Avoided (y)	Maximum Risk[a] of Lung Cancer (% reduction)	In first 100 years	Total	Groundwater Protected (y)
I	No controls.	Most likely	0	0	4 in 10^2 (0)	0	0	0
II	Institutional Control for 100 years	More likely	100	Hundred	2 in 10^2 (50)	700	2,800	100
III	Radon emission limit of 60 pCi/m^2s	Likely	Few 100	Hundreds	1 in 10^2 (80)	1,100	Thousands	Few 100
IV	Controls for 200-1000 years; Radon emission limit of 20 pCi/m^2s	Unlikely	1,000	Thousands	2 in 10^3 (95)	1,400	Tens of thousands	1,000
V	Controls for at least 1000 years; Radon emission limit of 20 pCi/m^2s	Unlikely	> 1,000	Many thousands	2 in 10^3 (95)	1,400	Tens of thousands	> 1,000
VI	Controls for at least 1000 years; Radon emission limit of 2 pCi/m^2s	Very unlikely	> 1,000	Many thousands	1 in 10^4 (>99)	> 1,400	Tens of thousands	> 1,000

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[a] Lifetime risk of fatal cancer to an individual assumed to be living 600 meters from center of a tailings pile.

[b] These estimates pertain to the control of 23 existing piles and future tailings projected to be generated through the year 2000 under the Baseline Industry Demand Scenario. Of the approximately 1400 deaths which are estimated to occur in the first 100 years under no control conditions, about 450 are the result of the existing tailings and 950 are due to future tailings.

Source: Derived from Table 4.3 and Chapter 10 of EIS.

Table S.2. Summary of Costs for Alternative Standards
(millions of 1981 dollars)

Alternative Standards	Assumed Control Methods	Economic Impact Case	Industry Costs, Undiscounted				Present Worth Costs(a) (10% discount rate)
			Existing Tailings	Future Tailings, Existing Mills(a)	Future Tailings, New Mills(a)	Total Cost(a)	
I	No controls	A	0	0	42(b)	42(b)	10
II	.5m earth cover, maintenance for 100 years	C	129	59	897	1085	337
III	1m earth cover, rock cover on slopes	E	151	93	952	1196	384
IV-a	3m earth cover, rock cover on slopes	H_1-M_1	250	133-610	1164	1547-2024	530-793
-b	3m earth cover, rock cover on slopes for existing tailings and 3m earth cover, below-grade disposal for new tailings	H_2-M_2	250	133-652	1244	1627-2146	549-834
V	3m earth cover, below-grade disposal	N	943	476	1373	2792	1333
VI	5m earth cover, rock cover on slopes	H_4-M_4	440	244-780	1526-1523	2210-2742	818-1115

(a) Baseline Industry Demand Scenario

(b) Cost of construction of initial embankments at new mills

Sources: Table 5.6 and Table 5.8

The alternative standards are expected to inhibit misuse of the tailings for periods ranging from zero years for Alternative I to greater than 1,000 years for Alternative VI. Starting from the no control standard, each succeeding alternative will provide increasing lengths of time over which we believe misuse will be inhibited. For measuring the prevention of surface spread of tailings, we use the estimated time period over which erosion of the tailings by wind and water would be avoided. Alternatives I, II, III, and IV would provide this protection for zero, one hundred, hundreds, and thousands of years, respectively. Alternatives V and VI would prevent erosion of the tailings for many thousands of years. For radon control, Alternative II would reduce emissions by 50 percent from the uncontrolled state, while Alternative III would result in an 80 percent reduction and Alternative IV a 95 percent reduction. Alternative V would also provide a 95 percent reduction in radon emissions, while Alternative VI would have a reduction of 99 percent from the uncontrolled condition. The radon deaths avoided by these controls and the maximum risk of lung cancer to individuals residing close to the piles which correspond to each alternative standard are shown in Table S.1. For groundwater protection, we estimate that the alternative standards would provide a range of protection from 100 years duration for Alternative II to 1,000 years or greater for Alternatives IV, V, and VI.

The costs of the alternative standards in Table S.2 are segmented by three categories of tailings: existing tailings, future tailings projected to be generated at mills which exist today, and future tailings projected for new mills. The future tailings are those which we estimate to be produced through the year 2000 according to the conditions of the baseline industry demand scenario. Costs were also estimated for an alternative projection of tailings generation (see Chapter 5). This breakdown of the cost estimates allows one to see the differences in cost for each alternative standard by each tailings category.

A range in costs is presented for Alternatives IV and VI which represents different assumptions on the implementation of groundwater protection requirements during the operational phase of a mill. The lower cost estimate assumes that all future tailings at existing mills are added to existing impoundments and disposed of (covered) together. No corrective actions at existing piles for compliance with groundwater protection requirements are assumed. The higher cost estimate assumes that all future tailings at existing mills are placed in new impoundments equipped with liners for groundwater protection and disposed of separately from the existing piles. We believe that the total cost for the industry will most likely fall within this range. Alternatives I, II, and III assume that future tailings at existing mills will be added to existing piles. Alternative V assumes that both future tailings and existing tailings are placed in new impoundments with protective liners.

For cost estimation purposes, Alternative IV has been divided into two cases which are represented by slightly different control methods assumed for compliance with the standard. Alternative IV-a assumes that all tailings are disposed of above-grade with a 3-meter earthen cover and rock cover on the slopes. Alternative IV-b assumes this control method for existing tailings piles, but new piles are assumed to be placed below-grade with a 3-meter cover. The range in the longevity requirement of this standard of 200 to 1000 years is responsible for the selection of the two possible outcomes for compliance. The difference in cost between Alternatives IV-a and IV-b is relatively small since the cost of rock cover for new tailings piles in IV-a nearly offsets the costs of placing the tailings below-grade. For the additional cost, Alternative IV-b realizes the incremental benefit of a longer period of misuse inhibition than Alternative IV-a since we believe that disposal below-grade will maintain the integrity of the earth cover for a longer time than rock cover on the slopes. The benefits of Alternative IV-b may be viewed as being the intermediate case between the benefits of Alternatives IV and V (as listed in Table S.1) since it assumes the Alternative IV control method for existing tailings and the Alternative V control method for new tailings piles. The longevity requirement of Alternative V, which calls for controls lasting at least 1000 years for all tailings categories, forces the moving of existing tailings and the disposal of all tailings below-grade.

Proposed Standards

Operations Standards

In accordance with the Act, the proposed operations standards for primary groundwater protection require that tailings impoundments be designed to prevent seepage of leachate from tailings into groundwater. Proposed secondary groundwater standards are based on the monitoring and response concept, consistent with SWDA, as amended. Nondegradation standards for groundwater are proposed for hazardous constituents that are in or can be derived from tailings, except for a short list of toxic materials for which concentration limits are proposed. In addition to the list of hazardous constituents specified under SWDA standards, the proposed standards add two hazardous elements commonly found in tailings: molybdenum and uranium. Concentration limits are also added for alpha radioactivity. If background levels or concentration limits are exceeded, a corrective action program consistent with SWDA, as amended, must be initiated as approved by the regulatory agency.

Existing standards and regulations for control of radionuclide particulate emissions to air under the AEA (40 CFR Part 190) and effluents to surface water under the CWA (40 CFR Part 440) for uranium mill tailings are not changed by the proposed standards. Radon emissions from uranium mill tailings during the operational phase of a mill are currently controlled by general NRC regulations (10 CFR Part 20) derived from Federal Radiation Protection Guidance and are not changed by these proposed standards.

Disposal Standards

Based on the benefit-cost analysis of control methods, we have chosen Alternative Standard IV for the proposed disposal standards. The proposed standards require that control of uranium byproduct materials be designed to provide reasonable assurance that releases of radon-222 to the atmosphere will not exceed an average rate of 20 picocuries per square meter per second. The standards require control of hazardous waste constituents listed under 40 CFR Part 261 to prevent their escape to ground or surface waters or to the atmosphere to the extent necessary to protect human health and the environment. Also, disposal of uranium mill tailings shall be done in a manner which minimizes the need for further maintenance.

The standards require that controls for uranium mill tailings be designed to be effective for up to one thousand years, to the extent reasonably achievable, and, as a minimum, at least 200 years.

Benefits of Proposed Standards

Under the proposed standards, the tailings would remain covered and isolated for 1,000 years or more. Therefore, we believe that the possibility of the misuse of most tailings will be unlikely for many thousands of years. Radon emissions from the disposed tailings will be significantly reduced from what they would be in an uncontrolled state. We estimate that the total deaths avoided by radon control alone would be many thousands during the first thousand years, compared to tailings which are left uncontrolled, and many tens of thousands over the entire useful life of the controls. The health risk to people living very near the tailings piles will be reduced from about 4 chances in 100 of fatal lung cancer during their lifetime to about 2 chances in 1,000. Also, groundwater would be protected for thousands of years under the proposed standards. Finally, the possibility of contamination of land by erosion of tailings would be virtually eliminated for many thousands of years.

Cost and Economic Impacts of Proposed Standards

We estimate that compliance with the proposed standards, if other regulatory requirements did not exist, would cost the uranium milling industry from about 550 million to 850 million dollars to dispose of all tailings which exist today at licensed sites, as well as those which we estimate will be generated by the year 2000, under baseline projection conditions. These costs are present worth estimates (discounted at a 10% rate) expressed on a 1981 constant dollar basis. The range in cost is due to different assumptions on the implications of the requirement for groundwater protection for future tailings at existing mills. The range of industry disposal costs becomes 450 million to 750 million dollars under low-growth projection conditions.

We estimate that the average uranium price may increase from 2 to 8 percent. In light of the currently poor economic condition of the industry and the threat of foreign competition, it is unlikely that mills will be able to pass through substantial portions of the disposal costs to their customers. Using our models, we estimate that if mills are forced to absorb the entire cost of disposal, one small mill may cease operation, depending on the implementation of the groundwater protection requirements. We further estimate that under the conditions of a more favorable cash-flow or a limited price pass-through, this single mill closure would be avoided. On the other hand, with no pass-through and a lower cash-flow, two small model mills and a large model mill may close.

These costs are not incremental costs of the proposed standards, since much of this cost would probably occur in the absence of the standards due to other regulatory requirements. These other requirements are Nuclear Regulatory Commission (NRC) licensing regulations and State regulations. We did not estimate the costs imposed by these other regulations because that would require a site-specific investigation. Since our standards are required by Congress to be of general application, we decided to develop a generic analysis based on model facilities. Therefore, we could not estimate the net impact of the proposed standards.

Regulatory Flexibility Analysis

The proposed standards would not have a significant impact on a substantial number of small entities, as specified under Section 605 of the Regulatory Flexibility Act (RFA). Therefore, we have not performed a Regulatory Flexibility Analysis. The basis for this finding is that of the 27 licensed uranium mills, only one qualifies as a small entity, and this mill will not be impacted by the standards. Almost all the mills are owned by large corporations. Three of the mills are partly-owned by companies that could qualify as small businesses, according to the Small Business Administration generic small entity definition of 500 employees. However, according to the RFA, a small business is one that is independently owned and operated. Since these three mills are not independently owned by small businesses, they are not small entities. The Regulatory Flexibility Act certification is presented in Appendix D of this RIA.

1. Introduction

The existence of large quantities of uranium mill tailings at uranium mill processing sites poses a significant hazard to health. Tailings are hazardous because: (1) breathing radon and its decay products exposes the lungs to alpha particles; (2) breathing particulates of thorium, uranium and their decay products exposes the lungs to alpha particles; (3) the body may be exposed to gamma rays; (4) radioactive materials and nonradioactive toxic elements from byproduct material may be swallowed with food and water. Since the radioactivity from these materials lasts for hundreds of thousands of years, the cumulative effects of tailings may be large. Detailed assessments of the hazards associated with human exposure to tailings are presented in the EIS. This RIA draws on those results for its quantitative assessment of the benefits of control of tailings.

Congress recognized this problem when it passed PL 95-604, the Uranium Mill Tailings Radiation Control Act of 1978 (the Act): "The Congress finds that uranium mill tailings located at active and inactive mill operations may pose a potential and significant radiation health hazard to the public....and that every reasonable effort should be made to provide for the stabilization, disposal and control in a safe and environmentally sound manner of such tailings." The Environmental Protection Agency was directed to set standards of general application which provide protection from the hazards associated with both the mill tailings at designated inactive sites of milling operations (Title I) and the processing and disposal of byproduct material at presently licensed and future mills (Title II). This RIA addresses only the proposed standards developed under Title II. The standards for inactive mill sites have been previously issued by the Agency.

Scope of Standards

There are two major parts of these proposed standards: control of releases from tailings during processing operations and protection from the tailings after disposal. However, this RIA addresses the proposed standards for tailings disposal only. This is because most of the requirements reflected by the operations standards are already in existence through regulations established under the Atomic Energy Act, the Clean Water Act, the Solid Waste Disposal Act, and the Act itself. Consequently, there are very few regulatory alternatives to be considered in the development of standards for control of mill tailings during the operational phase of a mill.

Uncontrolled releases during mill operations are limited to releases of radon since releases of all other radioactive effluents are regulated under the Environmental Radiation Protection Requirements for Normal Operations in the Uranium Fuel Cycle (40 CFR 190). Those standards, which apply during processing operations only, were published on January 13, 1977, and became effective for uranium mills and byproduct material on December 1, 1980. However, radon was excluded because of insufficient knowledge at the time 40 CFR 190 was established. EPA is not proposing control of radon from tailings during the operational phase since the health risk varies greatly from site to site and effective control methods which are economically feasible are not available at existing mills. We believe that the best approach to protecting people from radon emissions during operations is for the regulatory agencies to require combinations of controls at each site that maintain exposures to as low as reasonable levels.

During the operational phase of a uranium mill, discharges of process wastewater are controlled under the Clean Water Act. Currently, the regulations (40 CFR Part 440) require the use of "best practicable technology" for the control of effluents from uranium mills. Rules were proposed on June 14, 1982 (47 FR 25682, 40 CFR Part 440, Subpart E), to provide effluent limitation guidelines for "best available technology" and to establish new source performance standards under the Clean Water Act. These proposed rules specify that there shall be no discharge of process wastewater from uranium mills.

As required by the Act, protection of groundwater from hazardous materials in uranium tailings is to be provided by standards which are consistent with standards required under subtitle C of the Solid Waste Disposal Act (SWDA), as amended. EPA promulgated standards applicable to owners and operators of hazardous waste treatment, storage, and disposal facilities on July 26, 1982 (47 FR 32274, 40 CFR Part 261, Subpart F). These same SWDA standards, supplemented by a few additions at comparable levels of control for materials specific to uranium byproduct materials, are proposed in these standards. We also note that, independent of these proposed standards, the Act also requires NRC to implement the SWDA standards for groundwater protection in their licensing requirements for uranium mills. Consequently, uranium mills must comply with the SWDA groundwater protection standards even in the absence of these proposed standards.

Need for Standards

In recognition of the Agency's guidelines for preparing a regulatory impact analysis, we discuss why we believe there is a need for the proposed standards beyond the fact that Congress directed us to do so. There is a definite need for government intervention to mitigate this potential health hazard since there is no market mechanism which would provide health protection to the public. Disposal of mill tailings is not a revenue-producing activity because the mill tailings are essentially a waste product and have no value (although there is some small possibility for mineral recoverability). In addition to the absence of market forces to correct this problem, the lack of government control has increased the potential for adverse health effects to occur. In the past, members of the public not aware of the hazardous nature of tailings have hauled them away from inactive mill sites for use as a construction material for their homes. This greatly increases the health risk from the tailings from what it would be if the tailings were left untouched. We conclude that there is a need for government intervention to protect the public from the hazards associated with the existing tailings inventory and from future tailings generation.

Historically, there has been no Federal regulatory control of uranium mill tailings. Control of tailings was not included in the licensing procedures for uranium mills by the NRC (formerly the Atomic Energy Commission) because the tailings were not known to be hazardous and were not a controllable material under the AEA. With the passage of the Act, Congress included uranium mill tailings under the AEA, instructed EPA to develop generally applicable standards for control of mill tailings, and directed NRC to incorporate the EPA standards into their uranium mill licensing requirements. On October 3, 1980, NRC published final regulations for mill tailings disposal despite the absence of proposed EPA standards (45 FR 65521). In the preamble to their regulations, NRC recognized that their rules must be compatible with the EPA standards and stated that their "regulations will be revised, if required, when EPA standards are issued."

Currently licensed mills are located in seven States. Four of the States - Colorado, New Mexico, Texas, and Washington - are NRC Agreement States and have developed their own licensing regulations for uranium mills. These State regulations include the management of uranium mill tailings. Mills in the other three states - Utah, Wyoming, and South Dakota - are licensed by NRC directly. These two state groupings each represent about one-half of the total industry production. Consequently, there is a need for Federal intervention since relying on State regulations would only address one-half of the problem. Furthermore, the Act requires that regulations for mill tailings developed by the Agreement States should be "equivalent, to the extent practicable, or more stringent than standards" promulgated by NRC and EPA. Therefore, the State regulations are also dependent on the EPA standards.

Content of this RIA

In developing the regulatory options for this RIA, we have proceeded as if the NRC regulations had not been issued. The NRC rules emphasize requirements that a new mill must meet, but they state that regulations for existing sites cannot be developed in a generic fashion but must be considered on a site-by-site basis. In formulating the EPA regulatory options, we have segmented the uranium milling industry into existing and new mills and have examined the benefits, costs, and economic impacts of alternative levels of control on each segment.

In Chapter 2 of this RIA, we present a profile of the uranium milling industry and a characterization of the existing mill tailings inventory. Chapter 3 discusses the objectives of the standard and the alternative ways to achieve them. Chapter 4 presents a benefit-cost analysis of tailings disposal methods for existing and new tailings piles, on a model pile basis. Chapter 5 presents the industry cost and economic impact analysis of several combinations of disposal methods. Chapter 6 presents the rationale for choosing the proposed standards. Supporting documentation and data displays are contained in the Appendices.

This RIA contains all of the elements set forth in the Office of Management and Budget guidelines of June 5, 1981, for conformance with Executive Order 12291.

2. Industry Profile

This section develops background information on the structure and economic condition of the uranium mining and milling industry. The profile includes both historical and current data which form the foundation for the economic impact analysis. Projections of industry price, demand, and supply are developed in Appendix B.

The uranium industry is characterized by a relatively high degree of concentration with major publicly held corporations accounting for a large share of ownership in the industry. The industry experienced rapid growth in the early and mid-1970's that was stimulated by expectations of rapid increases in demand. The expectations of growth in demand proved to be too optimistic leading to supply outstripping demand and resulting in an economic slump for the industry. The industry is presently faced with excess capacity, large inventories, lower than expected demand, and the potential for increased competition from imports.

In a recent report on the domestic uranium industry, the U.S. Department of Energy summarized the situation this way: "It is now evident that the available domestic and foreign supplies for the 1980-1985 period is greater than the needs for those years. This situation is reflected in the occurrence of a significant drop in spot prices for uranium" (DOE81b).

2.1 Demand

2.1.1 The Nuclear Fuel Cycle

The uranium mining and milling industry is only one component of a much larger industry. The operations required to provide nuclear fuel for and to dispose of wastes from light water nuclear power reactors (LWRs) constitute the bulk of the U.S. nuclear fuel cycle. The various segments of the LWR nuclear fuel cycle are:

- Uranium mining and milling
- UF_6 conversion
- Isotopic enrichment
- UO_2 fuel fabrication
- Interim storage and transportation of spent fuel
- Disposal of spent fuel, or recovery of fissile material from spent fuel.

If the fissile fuel values are recovered, three additional fuel cycle segments are present. These are:

- Reprocessing
- Mixed oxide fuel fabrication
- Disposal of reprocessing and mixed oxide fuel fabrication wastes.

A schematic representation of the LWR fuel cycle is shown in Figure 2.1.

The generation of nuclear-powered electricity is the only major commercial source of demand for uranium in the United States, accounting for approximately 98 percent of total demand. Depleted uranium, a byproduct of the enrichment of natural uranium, is used in ordnance (military weaponry), for radiation shields, and in research. The supply of this byproduct greatly exceeds demand.

There are no substitutes for uranium in the production of nuclear energy by LWRs, although plutonium is a supplement. Lead, tungsten, and other heavy metals can replace uranium in nonnuclear applications.

Historical uranium concentrate production figures given in Table 2.1 show that the uranium industry had several periods of expansion and contraction. The U.S. Atomic Energy Commission (AEC) encouraged an expansion of the uranium industry following World War II by purchasing raw ore, and later yellowcake, building access roads and offering special incentives (Ta79). The expansion ended in the early 1960's when the AEC reduced purchases because U.S. military needs had been satisfied. The second major expansion began in the mid-1970's when confidence in the future of nuclear power was high and uranium prices had begun to climb. Production in 1980 reached nearly 20,000 metric tons of U_3O_8, an increase of 90 percent from the 1975 level of 10,500 metric tons.

Electricity generated by utilities supplies approximately 13 percent of the nation's total energy needs (DOE79). Nuclear power plants supply about 12 percent of the nation's electricity (SP81), or about 1.5 percent of total energy needs. Demand for electricity increased 3 percent from 1979 to 1980, much less than the 4.8 percent average yearly increase in demand over the past decade (DOE79). The slowdown in demand may be attributed to increases in the price of electricity due to higher fuel and capital costs and resulting conservation efforts.

Since there are no substitutes for uranium in the generation of nuclear-powered electricity, a continuing demand for uranium is expected. However, the rate of growth in future demand is unclear. Table 2.2 shows the number of nuclear plants ordered each year from 1966 through 1980. After 1973, the number of orders has fallen dramatically, from 25 in 1973 to two in 1978, and none since. Also, 50 contracts for nuclear reactors have been canceled since 1975, 16 in 1980 alone (BW81a). Many orders were canceled after the accident at Three Mile Island and were unexpected until that time. Also, 69 reactor projects were significantly delayed in 1980. Currently, there are approximately 70 nuclear power reactors licensed to operate in the U.S., and about 11 plants should begin operations in the next two years if the licensing process is not delayed (SP81).

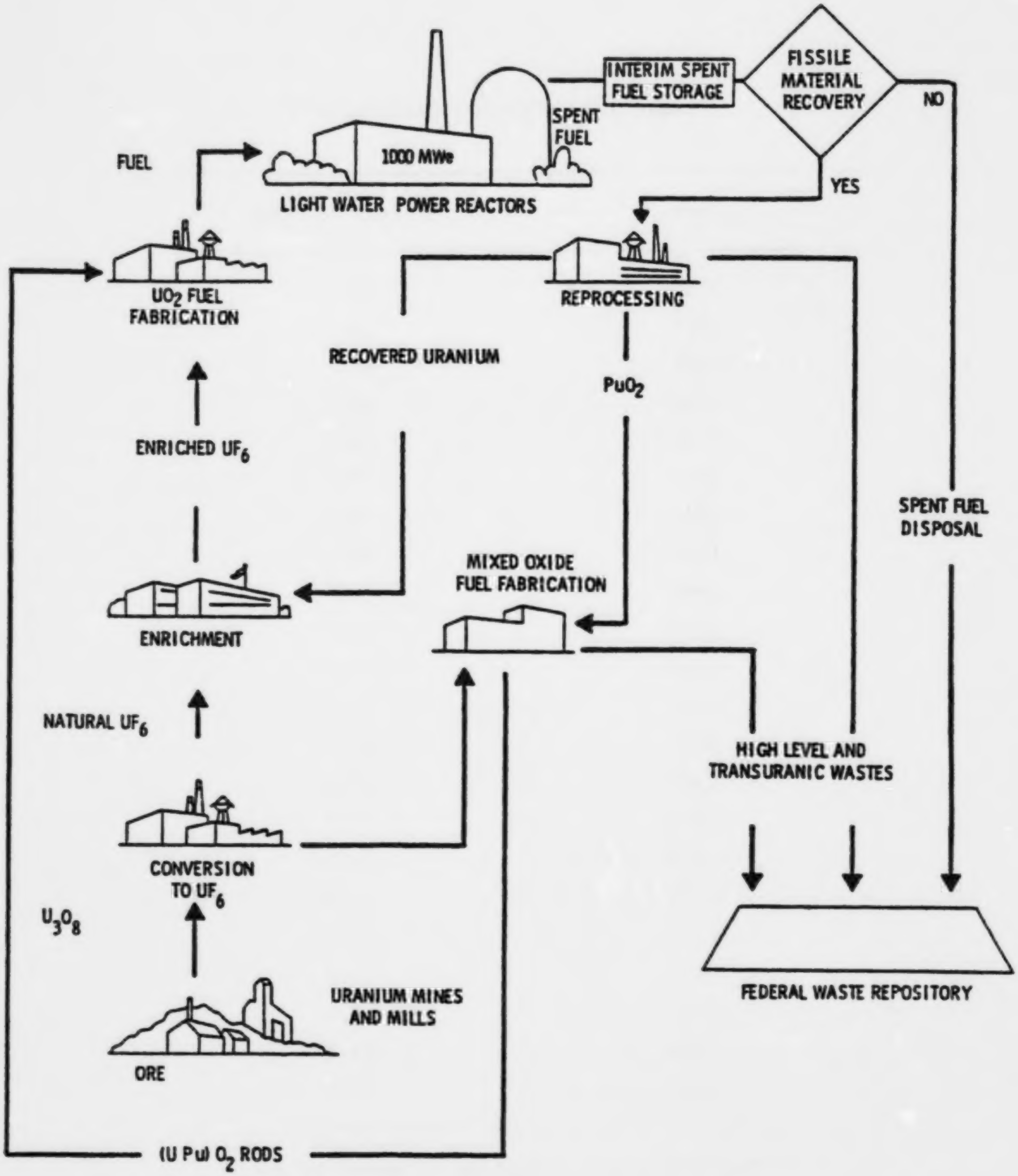
INTERIM SPENT FUEL STORAGE
FISSILE MATERIAL RECOVERY
NO
SPENT FUEL
FUEL
1000 MWe
LIGHT WATER POWER REACTORS
YES
UO2 FUEL FABRICATION
REPROCESSING
RECOVERED URANIUM
PuO2
ENRICHED UF6
SPENT FUEL DISPOSAL
MIXED OXIDE FUEL FABRICATION
ENRICHMENT
NATURAL UF6
HIGH LEVEL AND TRANSURANIC WASTES
CONVERSION TO UF6
U3O8
FEDERAL WASTE REPOSITORY
URANIUM MINES AND MILLS
ORE
(U Pu) O2 RODS

Figure 2.1. Light Water Reactor Fuel Cycle

Source: Battelle Pacific Northwest Laboratory, Fuel Cycle Cost Projections, prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-1041, December 1979.

Table 2.1. Uranium Production[a]

Year	Thousand MT U_3O_8
1960	16.0
1961	15.7
1962	15.4
1963	12.9
1964	10.7
1965	9.5
1966	9.6
1967	10.2
1968	11.2
1969	10.5
1970	11.7
1971	11.1
1972	11.7
1973	12.0
1974	10.5
1975	10.5
1976	11.6
1977	13.6
1978	16.8
1979	17.0
1980	19.8
1981	17.5

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[a] Includes U_3O_8 production obtained by mine water, heap leaching, solution mining, or as a byproduct of another activity. Production estimates from 1960 trough 1965 are Atomic Energy Commission concentrate purchases.

Source: Statistical Data of the Uranium Industry, U.S. Department of Energy, January 1982 (converted to metric tons).

Table 2.2. Historical Annual Nuclear Plant Ordering

Year Ordered	Number of Plants[a]	MWe[b]
Thru 1965	18	8,233.0
1966	20	16,594.0
1967	30	25,623.8
1968	14	12,895.0
1969	6	6,133.0
1970	13	13,681.0
1971	13	12,892.8
1972	21	23,456.0
1973	25	29,713.8
1974	11	13,441.0
1975	0	0
1976	1	1,270.0
1977	2	2,500.0
1978	2	2,240.0
1979	0	0
1980	0	0

(a)Does not include units ordered and cancelled prior to January 1, 1980.

(b)Does not incude 8 units totaling 301.3 MWe permanently shut down.

Source: Statistical Data of the Uranium Industry, U.S. Department of Energy, January 1, 1981.

Current issues concerning the safety of nuclear energy production, underscored by the accident at Three Mile Island, plus slower growth in the demand for electricity generated from all types of fuels, create considerable uncertainty in projections of the demand for uranium. Projections made in July 1978 of the annual uranium requirements of U.S. utilities for the years 1980 through 1986 were reduced as of December 1979 by an average annual amount of approximately 18 percent. Projections made in 1979 were also reduced during 1980.

In Appendix B we develop two projections of uranium industry demand for use in this RIA. These projections to the year 2000 are based on DOE forecasts of installed nuclear reactor generating capacity. These two projections, referred to as baseline demand and low-growth demand, provide a wide range of variation. Table 2.3 summarizes both the uranium demand and reactor capacity projections.

2.1.2 Elasticity of Demand for Uranium

There are no substitutes for uranium in the production of nuclear energy. Therefore, the demand for uranium is derived directly from the demand for nuclear-powered electricity. The demand for nuclear-powered electricity depends on the demand for electricity in general and the relative costs of alternative sources of electricity.

Utilities consider the costs of producing power and the reliability of the power source when deciding what type of power plant to build. The capital costs of a nuclear reactor are large, exceeding $1 billion for a typical 1,000 MWe plant. Fuel costs constitute a smaller proportion of the cost of nuclear electricity, averaging around 10 percent (Ta79). Once a utility has decided to build a nuclear power plant and has invested funds in construction, increases in fuel costs would not deter completion and operation of the plant. Therefore, the demand for uranium is insensitive to its price, especially in the short run. In other words, the demand for uranium is perfectly inelastic in the short run. In the long run, there may be some elasticity in the demand for uranium as the decision to build reactors may be influenced by the utilities' expectations about the cost of uranium.

2.1.3 Procurement and Pricing

Uranium is marketed and prices are quoted in the concentrate form, which is uranium oxide (U_3O_8), commonly referred to as yellowcake. There are three categories of uranium procurement: contract price, market price, and other. Contract price procurement involves agreeing on a price at the time the contract is signed, although physical delivery takes place in the future. Market price procurement bases the price of the contract on market prices at the time of delivery. Market price procurement may frequently include terms that establish a price floor, a cost floor, a ceiling price, or some combination of these. The "other" procurement type refers to arrangements that fall outside the contract or market price categories, such as captive production. Captive production relates to

Table 2.3. Summary of Projections for Uranium Demand and Installed Nuclear Reactor Capacity

Year	Reactor Capacity (GWe)	Yellowcake Requirements (Thousands of MT U_3O_8)	Conventional Mill Demand (Thousands of MT U_3O_8)
Baseline Industry Demand			
1980	54	14.2	12.5
1985	96	21.0	16.6
1990	128	25.5	18.1
1995	145	30.1	22.5
2000	175	36.2	28.4
Low Growth Industry Demand			
1980	54	14.2	12.5
1985	96	20.6	16.3
1990	122	22.9	16.3
1995	125	22.6	16.9
2000	120	18.9	14.8

buyers with direct control of uranium properties and accounts for about one-half of the "other" arrangements for deliveries from 1981 through 1990, according to DOE (DOE82b). Table 2.4 presents the distribution, by year of delivery, of the types of domestic uranium procurement for the 1979-1990 period. This table shows that about 80 percent of anticipated uranium deliveries from 1981 to 1990 will be purchased under either contract or market price contracts.

Before 1975, contract price procurement was used almost exclusively, while in the 1976-1981 period, procurement shifted significantly to market price contracts and other procurement. New procurement in 1980 consisted of 41 percent under contract price, 14 percent at market price, and 45 percent "other." However, new procurement in 1981 was 63 percent market, 20 percent "other," 7 percent contract, and 10 percent unpriced options.

Table 2.5 shows the average contract prices for 1981-1990 deliveries for which U.S. buyers and producers reported price data in DOE's January 1982 survey of uranium marketing activity. These prices are stated in year-of-delivery dollars and, therefore, reflect estimates of escalation in the contracts. Market price settlements for 1981 and 1982 are included with the contract prices since, as settled prices, they are similar to contract prices. The average uranium prices, as reported by buyers, increases from \$32.20 per pound in 1981 to \$58.35 per pound in 1989. The average price reported by producers increases from \$34.65 per pound in 1981 to \$57.35 in 1990.

Table 2.6 presents the average floor price of market price contracts for the period 1982-1990, as reported by buyers in the DOE survey. The average floor price, stated in year-of-delivery dollars, increases from \$51.85 per pound in 1982 to \$94.60 per pound in 1990. The DOE survey reports that 63 percent of the 1982-1990 market price commitments have a floor price, with price floors accounting for 56 percent and cost floors 7 percent.

Although most yellowcake is sold through long-term contracts rather than on the spot market, the spot market is important as an indicator of prices and the general financial health of the industry. The major participants in the spot market are the producers and the utilities. From 1972 to 1979 the price of uranium rose 700 percent from roughly \$6 per pound to over \$40 per pound. Starting in 1979, the spot price of uranium has experienced considerable weakness, declining from a high of \$43 to approximately \$17 per pound, as of September 1982. At a price of \$17 per pound, few domestic operations are profitable, even before additional pollution controls, due to general inflation and the increase in production costs due to a declining ore grade. Table 2.7 shows the average annual spot price of uranium.

Table 2.4. Types of Domestic Uranium Procurement Arrangements as of January 1, 1982

Year of Delivery	Percentage of Deliveries by Procurement Type		
	Contract Price	Market Price	Other
1979	72	22	6
1980	60	24	16
1981	58	30	12
1982	36	48	16
1983	24	60	16
1984	28	54	18
1985	26	56	18
1986	29	44	27
1987	31	42	27
1988	31	39	30
1989	30	36	34
1990	20	36	44
1981-1990	33	44	23

Source: U.S. Department of Energy, Survey of United States Uranium Marketing Activity, DOE/NE-0013/1, July 1982.

Table 2.5. Average U.S. Contract Prices & Market Price Settlements as of January 1, 1982

	Price Per Pound U_3O_8 (Year of Delivery Dollars)		Percent of Commitments with Reported Prices	
Year	Buyers	Producers	Buyers	Producers
1981	32.20(a)	34.65(a)	60(a)	90(a)
1982	38.15(a)	35.55(a)	74(a)	79(a)
1983	43.10	40.10(a)	89	81(a)
1984	50.45	39.55	49	86
1985	60.20	42.10	45	84
1986	51.35	45.60	32	100
1987	52.05	42.85	37	100
1988	53.10	41.95	59	100
1989	58.35	40.70	61	100
1990	(b)	57.60	(b)	100

(a) Includes settlements of market price contracts. The 1981 data do not include uranium delivered under litigation settlements.

(b) Not included because of limited data.

Source: U.S. Department of Energy, Survey of United States Uranium Marketing Activity, DOE/NE-0013/1, July 1982.

Table 2.6. Average Floor Prices of U.S. Market Price Contracts as Reported by Buyers (Year-of-Delivery Dollars)

Year	Price Per Pound U_3O_8	Percent of Commitments with Reported Floor Prices
1982	51.85	73
1983	55.45	75
1984	61.35	72
1985	66.05	73
1986	69.70	70
1987	76.05	59
1988	84.65	70
1989	88.55	75
1990	94.60	78

Source: U.S. Department of Energy, Survey of United States Uranium Marketing Activity, DOE/NE-0013/1, July 1982.

Table 2.7. Average Annual Spot Price for Uranium
(current dollars)

Year	Spot Price[a] (\$ per lb. U_3O_8)
1970	6.24
1971	6.48
1972	5.95
1973	6.41
1974	11.45
1975	23.68
1976	39.70
1977	42.20
1978	43.23
1979	42.57
1980	32.93
1981	25.00
1982[b]	17.00

[a] NUEXCO average annual price.

[b] Price as of September 1982.

Sources: American Metal Market,
Metal Statistics,
for selected years.

During the sixties and seventies, many uranium mines and mills operated with ore that contained approximately 0.2 percent uranium. Because the richer deposits have been exhausted, the ore grade in new mines has fallen to 0.10 to 0.15 percent uranium. The effect of the lower ore grade is to increase costs because each ton of ore that is mined yields less salable product.

2.2 Supply

Major sources of supply of uranium in the United States are domestic mining and milling operations, domestic inventories, and imports of foreign uranium. Besides conventional uranium mills, domestic yellowcake is produced from solution mining, mine water, heap leaching, or as a byproduct of another activity (such as phosphoric acid production). Historically, about 90 percent or more of yellowcake has been produced by conventional mills. However, in 1980, the conventional mill share was 85 percent (DOE81a), while in 1981 it was 31 percent (DOE82a).

Sharp increases occurred in the price of uranium in the mid-1970's that stimulated new mining activity. Milling capacity also increased in the last decade, nearly doubling from about 24,000 MT ore/day in 1975 to a level of about 46,000 MT ore/day in January 1981. Table 2.8 shows the capacity of conventional mills and the capacity utilization rate for the years 1975 through 1982. The increased mining and milling activity coupled with reduced demand projections for nuclear power created a surplus of uranium in 1980. During 1981 and 1982, eight mills, accounting for capacity of 17,600 MT ore/day, ceased operations, while the average capacity utilization rate for the industry as of September 1982 was only 69 percent. Some mills are operating at as little as 20 percent capacity (deV82).

Based on projections of the demand for electricity and the expected expansion of nuclear power, utilities began making commitments to purchase large amounts of uranium in the mid-1970's. By 1980, utility inventories were at record high levels, the demand for electricity in general was lower than the expected level, and concern was widespread over the accident that shut down the Three Mile Island No. 2 reactor. During the time leading up to and following these events, a number of nuclear reactor orders were cancelled. An indication of the high level of inventories is that utilities sold a portion of their uranium inventories on the spot market in early 1980 when uranium prices were higher (CRB80). Table 2.9 shows inventory levels on January 1 for 1980, 1981, and 1982. Inventory to meet one year of the utilities' needs is considered to be adequate (Co79). As of January 1982, utilities were holding 47,900 metric tons of uranium. This figure is about 6.5 times greater than the estimated 1980 consumption by utilities of 7575 metric tons (CRB81), and about 2.5 times greater than 1981 total uranium production of 17,500 metric tons.

An additional source of supply of uranium for the United States comes from imports. Imports of foreign uranium constitute approximately 8 percent of total U.S. consumption, and this percentage is expected to grow. Section 2.2.2 discusses imports and exports of uranium in detail.

Table 2.8. Conventional Uranium Mill Nominal Capacity and Utilization Rates

Year	Nominal Capacity, as of January 1 of each year (Metric Tons Ore/Day)	Capacity Utilization Rate (Percent)
1975	24,180	83
1976	25,810	87
1977	28,270	75
1978	35,520	91
1979	39,740	90
1980	44,500	NA
1981	46,300	NA
1982 (Jan.)	45,200	NA
1982 (Sep.)	31,100	69

NA = Not available.

Sources: Nominal capacity as of January 1 for each year is from U.S. Department of Energy, Statistical Data of the Uranium Industry, selected years.

Capacity utilization rates for 1975-1979 is from U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, September 1980.

Capacity and utilization rate for September 1982 is from Paul C. deVergie, et al., "Production Capability of the U.S. Uranium Industry," presented at Nuclear Assurance Corporation Uranium Colloquium V, Grand Junction, Colorado, October 6-7, 1982.

Table 2.9. Uranium Inventories Held by Buyers
(Metric Tons U_3O_8 Equivalent)

	All Buyers As Of			Utilities As Of		
	1/1/80	1/1/81	1/1/82	1/1/80	1/1/81	1/1/82
Natural Uranium	32,750	40,910	46,450	25,040	34,200	40,000
(Foreign-Origin)	(4,810)	(4,540)	(4,900)	(3,080)	(3,180)	(3,810)
Enriched Uranium	14,700	16,600	10,160	13,790	15,150	7,890
(Foreign-Origin)	(360)	(630)	(270)	(360)	(540)	(270)
Total Uranium	47,450	57,510	56,610	38,830	49,350	47,900
(Foreign-Origin)	(5,170)	(5,170)	(5,170)	(3,440)	(3,720)	(4,080)

Source: Survey of United States Uranium Marketing Activity, U.S. Department of Energy, July 1982 (converted to metric tons).

Note: Numbers may not add to totals due to independent rounding.

2.2.1 Uranium Mill Location, Ownership, and Operating Status

The focus of this RIA is the conventional uranium milling segment of the industry. As of September 1982, there were 27 licensed conventional uranium mills of which only 16 were operating (deV82). The conventional mills are located in the western States of Colorado, New Mexico, Washington, Wyoming, Utah, South Dakota, and Texas. As of January 1980, 21 mills were operating and had tailings piles. Two other licensed mills (Edgemont, South Dakota, and Ray Point, Texas) had tailings piles but were no longer operating. The quantity of tailings existing at the 23 sites at the beginning of 1980 was about 146 million metric tons. Table 2.10 gives the location, ownership, capacity, tons and acreage of mill tailings, and operating status for each of the 27 conventional mills.

Horizontal integration occurs when a company produces more than one type of product, or when a company purchases or merges with a competitor. In the late 1940's there were many purchases and mergers of small uranium mining firms which resulted in the formation of the United Nuclear Corporation. A subsequent joint venture between United Nuclear and Homestake Mining Company established a substantial operation, measured by both reserves and milling capacity (Ta79).

More recently, there are 23 companies that own conventional uranium milling operations. Major oil and mining companies are prominent in the industry. Kerr-McGee, Atlantic Richfield (Anaconda), Exxon, Getty Oil (Petrotomics), Phelps Dodge (Western Nuclear), and Newmont (Dawn) mill uranium. Other large producers include Union Carbide, UNC Resources (formerly United Nuclear), and Pathfinder Mines (an independent subsidiary of General Electric). Many of the companies that are prominent in the uranium industry are also prominent in mining other metals.

Concentration ratios for the uranium milling industry are shown in Table 2.11 for selected years from 1971 to 1982. The peak concentration, as measured by the eight-firm ratio, occurred in 1975 as this ratio reached 88 percent. As of January 1982, the eight leading milling companies accounted for 67 percent of the industry capacity.

Vertical integration can occur in the uranium industry if a company engaged in other activities required for the generation of nuclear power merges with a uranium mining firm. For example, General Electric (GE), the second largest vendor of nuclear reactors, acquired uranium holdings when it merged with Utah International in 1975. The Department of Justice required GE to spin off its uranium holdings into an independent subsidiary, the Lucky McCorporation, which changed its name to Pathfinder Mines Corporation in 1978. GE recently sold 80 percent of its interest in the Pathfinder uranium mills to the French company, Cogema. In addition to vertical integration between nuclear reactor manufacturers and uranium mining firms, there is also considerable vertical integration between

Table 2.10. Status of Licensed Conventional Mill Sites in the United States

State	Location	Name and/or Owner	Year Mill Started	Max. Licensed Mill Capacity (MT Ore/Day)	MT of Tailings[a] (Thousands)	Size of Tailings Pile[a] (Acres)	Operating Status[b]
Colorado	Canon City	Cotter Corp.	1958	1,300	1,000	200	Active
	Uravan	Union Carbide Corp.	1950	1,200[c]	8,825	79	Active
New Mexico	Seboyeta	Sohio-Reserve	1976	1,500	1,400	100	Closed
	Church Rock	United Nuclear Corp.	1977	3,600	2,200	200	Closed
	Bluewater	Anaconda	1953	5,400	17,100	270	Closed
	Ambrosia Lake	Kerr-McGee Nuclear Corp.	1958	6,300	24,600	260	Active
	Milan	Homestake Mining Co.	1958	3,200	17,900[d]	210[e]	Active
	Marquez	Bokum Resources Corp.	-	2,000	-	-	Closed
South Dakota	Edgemont	Tennessee Valley Authority	1956	500	2,760	82	Closed
Texas	Panna Maria	Chevron	1979	2,200	1,200	250	Active
	Falls City	Conoco and Pioneer-Nuclear Inc.	1972	2,900	5,600	220	Closed
	Ray Point	Exxon, USA (Susquehanna-Western)	1970	800	1,706	50	Closed
Utah	Blanding	Energy Fuels Nuclear	1980	1,800	-	333	Active
	La Sal	Rio Algom Corp.	1972	640	1,600	35	Active
	Moab	Atlas Corp.	1956	1,100	7,800	115	Active
	Hanksville	Plateau Resources, LTD.	1982	680	-	-	Closed
Washington	Ford	Dawn Mining Co.	1957	400	2,800	106	Active
	Wellpinit	Western Nuclear	1978	1,800	1,300	42	Closed
Wyoming	Gas Hills	Federal-American Partners	1959	900	4,200	105	Closed
	Gas Hills	Pathfinder Mines Corp.	1958	2,000	5,500	150	Active
	Powder River (Bear Creek)	Rocky Mountain Energy/Mono Power	1977	1,800	8,000	150	Active
	Powder River (Highland)	Exxon, USA	1972	2,700	5,700	200	Active
	Jeffrey City	Western Nuclear Corp.	1957	1,500	11,000	85	Closed
	Gas Hills	Union Carbide Corp.	1960	1,200	7,600	174	Active
	Shirley Basin	Pathfinder Mines Corp.	1971	1,600	4,233	150	Active
	Shirley Basin	Petrotomics Co.	1962	1,500	2,000	160	Active
	Red Desert	Minerals Exploration Co.	1981	2,700	-	-	Active
			TOTALS		146,024	3,726	

(a) As of January 1, 1980.

(b) As of September 1, 1982.

(c) Ore processed at the Vanadium facility for the Manhattan project in 1943.

(d) Includes 1,200,000 tons from salvaged Homestake - New Mexico Partners Mill that was located on the present site.

(e) Includes 50 acres from salvaged Homestake - New Mexico Partners Mill that was located on the present site.

Table 2.11. Concentration in the Uranium Industry by Milling Capacity
(Percent)

	1971	1975	1977	1980	1982
2 Firms	35	39	34	27	26
4 Firms	54	62	54	45	42
8 Firms	78	88	83	71	67

Sources: For the years 1971, 1975, and 1977, June Taylor and Michael Yokell, Yellowcake, The International Uranium Cartel, 1979. The years 1980 and 1982 were estimated from data in U.S. Department of Energy, Statistical Data of the Uranium Industry, GJO-100(80), 1981, and GJO-100(82), 1982.

utilities and mining firms. For example, utilities such as Commonwealth Edison, Consumers Power Company, Niagara Mohawk, and Southern California Edison own or exercise substantial control over uranium mining firms. As noted in Appendix A, approximately 70 percent of uranium is milled as part of an integrated mining and milling operation. At the mills, approximately 10 to 15 percent of production is "captive" production of the owners of later stages of production.

2.2.2 Imports and Exports

A significant factor that determines import levels, and thus affects the supply of uranium for domestic uses, is United States Government policy. The Department of Energy (DOE) is the only domestic processor allowed to enrich yellowcake (U_3O_8) with the isotope Uranium 235 for nuclear applications. Imports of uranium to be enriched for U.S. usage were banned from 1964 to 1976. Foreign uranium was allowed to be enriched in the U.S. and returned to the country of origin during this period. This ban, which was effectively a subsidy to the domestic uranium industry, was partially lifted in 1977 when 10 percent of each U.S. utility's enriched uranium was allowed to be of foreign origin. An additional 10 percent allowance is added each year until 1984, when the current restriction on enrichment of imported uranium is due to expire. However, due to the depressed condition of the uranium industry, Congress is considering reducing, or continuing to limit, imports of uranium for commercial uses. Therefore, this potential Congressional action introduces an additional element of uncertainty into the uranium market.

The actual use of foreign uranium in the U.S. can be measured by the amount enriched at the DOE processing plants. Table 2.12 shows the receipts of uranium at DOE plants classified by origin. The data show that U.S. utilities as a whole are purchasing substantially less foreign uranium for enrichment than the percentage allowed by U.S. policy. In 1981, when the allowable foreign origin limit of an individual utility's deliveries to enrichment was 40 percent, only 10.1 percent of all utilities' deliveries were of foreign origin.

The United States exports uranium to other countries. Table 2.13 gives historical data on U.S. imports and exports. Until 1975, the U.S. was a net exporter of uranium, with exports averaging 6 percent of domestic production. From 1975 through 1977, U.S. imports were greater than exports. Net imports represented 5 percent of domestic production during this period. In 1978, the U.S. became a net exporter of uranium again and remained so through 1980. Net exports averaged about 6 percent of production from 1978 through 1980. In 1981, the United States once again became a net importer of uranium. Currently, France and Taiwan are among the countries purchasing U.S. uranium. However, both Canada and Australia contain substantial reserves of low cost deposits of uranium,

Table 2.12. Deliveries of Uranium to DOE Enrichment Plants by Domestic Customers

Year	Origin (Metric Tons of U_3O_8)			Percent Foreign	
	U.S.	Foreign	Total	Actual	Allowable
1977	12,918	638	13,556	4.7	10
1978	10,847	660	11,507	5.7	15
1979	14,003	1,443	15,446	9.3	20
1980	10,101	1,126	11,227	10.0	30
1981	9,133	1,027	10,160	10.1	40

Source: Survey of United States Uranium Marketing Activity, U.S. Department of Energy, July 1982 (converted to metric tons).

Table 2.13. U.S. Imports and Exports of Uranium (U_3O_8) for Commercial Uses

Year	Imports (Metric Tons)	Exports (Metric Tons)
1966	0	363
1967	0	635
1968	0	726
1969	0	454
1970	0	1,905
1971	0	181
1972	0	91
1973	0	544
1974	0	1,360
1975	600	500
1976	1,600	500
1977	2,500	1,800
1978	2,400	3,000
1979	1,400	2,800
1980	1,600	2,600
1981	3,000	2,000

Source: *Survey of U.S. Uranium Marketing Activity*, U.S. Department of Energy, July 1982 (converted to metric tons).

and South Africa is increasing its production capacity. U.S. producers will be faced with competition, both domestically and in the export market, from two huge Australian uranium projects scheduled to begin production within two years (CRB80). In South Africa, uranium is produced at low cost because it is a byproduct of gold mining. United States production costs are higher due to lower ore grades, strict mine safety requirements, and smaller sized mines (DOE81b).

Predicting the degree of reliance on imported uranium for future domestic use is very uncertain. Putting the potential import restrictions aside, the use of foreign uranium, though economic, appears to be limited for other reasons. With a significant reliance on imports, U.S. utilities, and the nation as a whole, may be vulnerable to a Mid-East oil-type embargo which could result in substantial price increases and curtailments of supplies. Since nuclear reactors are designed for thirty to forty years of operation, utilities need a uranium supply for a long time frame. There is evidence that U.S. utilities would be willing to pay a premium for U.S. supplied uranium in order to get a reliable supply of fuel over a long time period (Re81). Utility spokesmen, both in favor and against import restrictions, have often stated that it is essential to have a stable domestic uranium production industry capable of meeting electric utilities' needs when called upon (Hu82, Ma82). The "Buy American" philosophy seems to be a real phenomenon in the uranium business. It is felt that U.S. mills will set prices due to U.S. buyer preference for domestic uranium (Ha82). On the other hand, though, pressure from Public Utility Commissions to minimize costs will force utilities to purchase uranium that is the most economic. Consequently, we cannot accurately forecast the role of imports in future uranium requirements.

2.2.3 Uranium Reserves

The United States has the largest known uranium deposits in the world. Thus, the potential U.S. supply of uranium is more than adequate to meet demand. Of the total "reasonably assured" world reserves, the United States has 25 percent, Australia - 18 percent, Sweden - 17 percent, South Africa - 15 percent, and Canada - 9 percent (Ta79). Reserves is a term given to resources that are known to exist because of information gathered by drilling. Table 2.14 shows historical estimates of uranium reserves in the United States. The reserves are listed by "forward cost" categories, e.g., $15/lb. Forward costs include operating and capital costs, in current dollars, that must be incurred to produce the uranium (DOE80). Not included in forward costs are all previous exploration and development expenses, and future income taxes, profits, and the cost of money. It is common practice in the uranium industry to multiply the forward costs by 1.7 to obtain full costs (Se80).

Table 2.14. Historical Estimates of Uranium Reserves

As Of	Thousand MT U_3O_8			
	$15/lb	$30/lb	$50/lb	$100/lb
1969	288			
1970	355			
1971	472			
1972	472			
1973	472	575		
1974	380	544		
1975	390	581		
1976	372	617	762	
1977	336	626	807	
1978	263	626	835	
1979	204	585	849	1,018
1980	102	426	714	938
1981	0	186	539	811

Note: Reserves reported at $30, $50, and $100/lb include reserves in all lower cost categories. This table does not include byproduct uranium.

Source: Statistical Data of the Uranium Industry, U.S. Department of Energy, January 1, 1982 (converted to metric tons).

2.2.4 Employment

Overall employment in the uranium industry is shown on Table 2.15, for the years 1973 through 1979. The growth in employment in the industry is indicative of the prosperity the industry was enjoying during this period. From 1973 to 1979 total employment increased more than three-fold.

Detailed employment data for the uranium mining and milling segments of the industry are shown separately in Table 2.15a for the year 1979. Total employment totaled 15,991 people for the two segments in 1979, up from a total of 15,124 in 1978. By 1981, however, more than one-third of the uranium mining and milling workers had been laid off as employment totaled only 9,840 workers (DOE82a).

2.3 Financial Condition

The uranium industry is currently in a period of contraction. The spot price of uranium averaged only $25 per pound in 1981, while production costs in the U.S. average about $30 per pound (BW81b). Since many domestic operations are unprofitable when uranium is selling at so low a price, many have closed or delayed mining and milling projects. The outlook for a rise in prices in unclear. Uranium prices will rise when more nuclear reactors are built and licensed, and analysts are unsure when the nuclear power industry will begin to expand.

Financial data for six companies in the uranium industry are shown in Tables 2.16 and 2.17, covering the period 1976 through 1980. As a group, these six companies provide a reasonable financial representation of the uranium industry. Tables 2.16 and 2.17 show considerable variations in the data both within companies and between companies. In general, the tables indicate the declining financial health of the industry. The financial information has been assembled from corporate annual reports and Securities and Exchange Commission (SEC) 10-K reports. Many companies in the uranium industry have more than one business segment. The information in the tables is from the business segment that includes uranium, although other products may also be included, such as other metals. Therefore, the data should be compared over several years and among several companies to develop a profile of a typical uranium company.

Capital investment expenditures for the domestic uranium mining and milling segments are shown in Table 2.18. Total capital expenditures rose at an average annual rate of 29 percent from 1975 to 1980. Expenditures for 1981 totaled $271 million, a decrease of 47 percent from the 1980 level of $515 million. Planned expenditures for 1982 and 1983, estimated to be $128 and $100 million, respectively, reflect a continuation of the decline in capital investment.

Table 2.15. Employment in the Uranium Industry

	1973	1974	1975	1976	1977	1978	1979
Exploration	1,557	1,697	2,049	2,793	4,140	4,449	4,066
Mining	3,516	3,928	5,386	7,603	11,453	13,338	14,219
Milling	1,522	1,668	2,237	2,727	3,175	3,615	3,476
Total	6,595	7,293	9,672	13,123	18,768	21,402	21,761

Source: U.S. Department of Energy, Office of Uranium Resources and Enrichment, "The Domestic Uranium Industry and Imports of Uranium," February 23, 1981.

Table 2.15a. Employment in the Uranium Mining and Milling Industries (1979)

	Underground		Open Pit							
	Miners	Serv. & Support	Miners	Serv. & Support	Operations	Maintenance	Technical	Other	Supervisory	Total
Mining(a)										
Colorado and Utah	891	471	90	6	NA	NA	124	273	213	2,068
New Mexico	1,843	1,836	338	237	NA	NA	496	361	555	5,666
Wyoming	278	310	1,424	1,012	NA	NA	381	289	353	4,047
Other States	52	25	459	216	NA	NA	69	61	92	974
Total	3,064	2,642	2,311	1,471			1,070	984	1,213	12,755
Milling										
Colorado and Utah	NA	NA	NA	NA	289	246	117	41	103	796
New Mexico	NA	NA	NA	NA	449	342	103	81	185	1,160
Wyoming	NA	NA	NA	NA	288	238	117	113	142	898
Other States	NA	NA	NA	NA	139	125	31	36	51	382
Total					1,165	951	368	271	481	3,236

NA = Not Applicable.

(a) The figures include 323 truckers and 430 employees involved in shaft sinking. Not included are 1,464 employees working in recovery of uranium from byproducts and solution mining, and 240 employees working on construction of uranium recovery facilities.

Note: This table was prepared from information obtained from companies and individuals engaged in mining and milling uranium. The numbers are the average employment for calendar year 1979.

Source: Statistical Data of the Uranium Industry, U.S. Department of Energy, January 1, 1980.

Table 2.16. Financial Information for Selected Companies in the Uranium Industry

($ in Thousands)

	Year	Atlas	Conoco	Homestake	Kerr-McGee	Pioneer	UNC
Revenues	1976	15,611	NA	22,441	96,800	NA	29,339
	1977	28,152	NA	59,141	123,300	NA	80,816
	1978	26,845	16,488	44,928	115,200	13,810	133,193
	1979	38,253	16,384	42,388	163,400	20,267	181,626
	1980	60,148	34,586	45,363	238,900	7,829	167,811
Operating Profit	1976	4,607	NA	10,389	32,700	NA	7,103
	1977	8,027	NA	24,622	22,300	NA	28,539
	1978	(1,925)	(20,815)	20,454	20,100	1,257	42,320
	1979	(2,159)	(21,530)	14,097	(200)	(1,004)	61,339
	1980	6,142	(30,719)	(601)[a]	30,000	(1,082)	12,243
Assets	1976	NA	NA	14,144	215,300	NA	87,222
	1977	NA	NA	45,023	236,500	NA	145,376
	1978	56,375	52,491	42,990	272,000	51,119	203,041
	1979	79,428	61,218	47,790	288,400	70,583	279,436
	1980	72,834	62,867	54,798	304,800	84,046	239,888
Depreciation Depletion	1976	NA	NA	192	7,500	NA	1,070
	1977	NA	NA	80	9,300	NA	1,952
	1978	3,331	2,876	0	13,800	8,679	5,414
	1979	4,058	3,209	17	15,600	11,253	9,677
	1980	6,212	3,957	6,980	21,300	8,718	11,952
Capital Expend.	1976	NA	NA	2,036	NA	NA	27,856
	1977	NA	NA	2,628	NA	NA	54,499
	1978	14,579	7,213	7,961	NA	19,467	49,518
	1979	21,870	6,937	8,533	NA	23,513	39,156
	1980	7,453	7,999	12,521	NA	17,567	46,662

NA = Not Available.

(a) Includes an $8,075 loss on settlement of uranium litigation, would otherwise have been (8,075) - 601 = +$7,474.

Source: Corporate annual reports, Securities and Exchange Commission (SEC) 10-K reports.

Table 2.17. Financial Ratios for Selected Companies in the Uranium Industry
(Percentage)

	Year	Atlas	Conoco	Homestake	Kerr-McGee	Pioneer	UNC
Operating Profit/ Revenue	1976	29.5	NA	46.3	33.8	NA	24.2
	1977	28.5	NA	41.6	18.1	NA	35.3
	1978	-	-	45.5	17.4	9.1	31.8
	1979	-	-	33.3	-	-	33.8
	1980	10.2	-	16.5(a)	12.6	-	7.3
Operating Profit/ Assets	1976	NA	NA	73.4	15.2	NA	8.1
	1977	NA	NA	54.7	9.4	NA	19.6
	1978	-	-	47.6	7.4	2.5	20.8
	1979	-	-	29.5	-	-	22.0
	1980	8.4	-	13.6(b)	9.8	-	5.1
Depreciation Depletion/ Revenues	1976	NA	NA	1.8	7.7	NA	3.6
	1977	NA	NA	.3	7.5	NA	2.4
	1978	12.4	17.4	-	12.0	62.8	4.1
	1979	10.6	19.6	.04	9.5	55.5	5.3
	1980	10.3	11.4	15.4	8.9	111.0	7.1
Capital Expenditure/ Revenue	1976	NA	NA	9.1	NA	NA	95.0
	1977	NA	NA	4.4	NA	NA	67.4
	1978	54.3	43.7	17.7	NA	141.0	37.2
	1979	57.2	42.3	20.1	NA	116.0	21.6
	1980	12.4	23.1	27.6	NA	224.0	27.8

NA = Not Available.

- = Loss Year.

(a)16.5 percent without litigation.

(b)13.6 percent without litigation.

Source: Corporate annual reports, Securities and Exchange Commission (SEC) 10-K reports.

Table 2.18. Capital Investment for Domestic Uranium Production

	1975	1976	1977	1978	1979	1980	1981	1982 (Planned)	1983 (Planned)
Mine									
Companies Reporting	22	29	31	25	26	34	29	20	17
Expenditures ($ Millions)	124	200	325	271	282	273	212	105	90
Mill									
Companies Reporting	18	24	26	19	26	27	22	14	13
Expenditures ($ Millions)	22	55	167	156	203	242	59	23	10
Total Expenditures ($ Millions)	146	255	492	427	485	515	271	128	100

Note: Based upon surveys conducted from January 1, 1976, to January 1, 1982.

Source: Statistical Data of the Uranium Industry, U.S. Department of Energy, January 1, 1982.

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3. Objectives of Standards and Control Methods

3.1 Goals of Radiation Protection for Tailings Disposal

Standards for the protection of public health, safety and the environment must be written to address predetermined objectives or goals. We have identified five goals which describe the purpose in developing these standards. These goals are:

1. Prevent future uses of tailings, especially in or near dwellings or workplaces. The past use of tailings as construction materials has caused increases in the levels of radon decay products in buildings. People in these buildings have a much greater risk of radiation-induced lung cancer.

2. Protect the population from radon decay products emanating from tailings piles. Radon exposures to people living in the vicinity of tailings piles can be above background and thus lead to increased risk to these individuals. Also, since radon is a noble gas with a radioactive half-life of 3.8 days, any radon released from tailings can travel long distances before it decays to innocuous levels. As the radon decays, the decay products expose large numbers of people to very low levels of radiation. Since any level of radiation exposure presents some risk to humans, reduction of this risk must be considered regardless of how small the risk to any one individual.

3. Prevent the surface spread of tailings. Tailings are spread about the local area by wind and precipitation. This causes radiation exposure to the local residents from both radon decay products and external gamma radiation. Tailings can be a significant source of external gamma radiation at low concentrations in soil. NCRP #45 (NP75) recommends using a dose conversion factor of 13.9 mrem per year per pCi of Ra-226 per gram of soil covering a large area for external gamma radiation. Thus, relatively low concentrations in soil can lead to annual doses approaching natural background radiation levels of about 100 mrem per year. In addition, the spread of tailings may contaminate surface water resources. The health risk depends on the amount of dispersed tailings and varies at the different sites. At some sites it is estimated this may be a significant risk.

4. Protect groundwater sources. Contamination of groundwater occurs when water comes in contact with tailings, leaches hazardous or toxic materials from the tailings, and then moves into groundwater aquifers through fissures, percolation, or other means. This water contains nonradioactive contaminants as well as radioactive contaminants. Some evidence indicates that when a pile is no longer used and dries out, most of the contamination stops. The health risk depends on the contaminant concentrations in the water and the uses of the water (human consumption, livestock watering, irrigation, etc.).

5. Provide control of the tailings for very long times. Because of the long lifetimes of the radioactive contaminants (thorium-230, for example, has a half-life of about 75,000 years) and the presence of other toxic materials (which never decay), the potential for harming people will persist indefinitely. Many interrelated factors affect the long-term performance of tailings disposal methods. They include external phenomena, such as erosion, earthquakes, floods, windstorms, and glaciers; internal chemical and mechanical processes; and human activities. Predictions of the stability of disposed tailings become less certain as the time period increases. Beyond several thousand years, long-term geological processes and climatic change will determine the effectiveness of most "permanent" control methods.

To accomplish the above objectives, we have translated the first four goals of the standards into categories of regulatory controls. Protection for long periods of time, goal number five, applies to each of the other objectives and is discussed in Section 3.3. These controls are listed in four general classes:

I. prevention of misuse;

II. radon control;

III. prevention of the spread of radioactive materials by wind and surface water;

IV. prevention of groundwater contamination.

It should be understood that some of these classes are interrelated. For instance, radon control can be achieved by placing a thick earth cover over the tailings. This method also provides significant control for groundwater protection and prevention of misuse. Despite the fact that these classes of control are not mutually exclusive, this classification appears to offer a reasonable approach for analyzing control methods and developing regulatory options.

These four classes and the likely methods of providing such controls are discussed in the following sections.

3.2 Control Methods

3.2.1 Prevention of Misuse

Materials contaminated with radium-226 and thorium-230 must be isolated so that they are not readily available for use in the construction of dwellings and other occupiable buildings. Isolation is also required to prevent the construction of dwellings directly on disposed tailings when institutional controls fail sometime in the future. Tailings are a high grade sand and can be ideal for use in construction or as fill, if the material were not a health hazard. There is real potential for harm if, as happened in Grand Junction, Colorado, people identify a disposal site as a resource area for sand. (The reader should refer to the EIS for more information on the Grand Junction experience.)

Various methods can be used for isolating the tailings ranging from a simple earthen cover to a deep mine. Greater amounts of material, such as earth, placed between the tailings and the environment increase the isolation of the tailings. When considered in this way, greater, or better, isolation means there is a smaller likelihood that man will intrude into the disposed tailings.

The readily available method of tailings disposal is covering the tailings with earth. Other methods are possible but are also more costly. Therefore, this analysis limits the consideration of isolation methods to those involving earthen covers. However, it is recognized that some day other methods providing better isolation may become economically competitive.

The amount or thickness of soil needed to provide isolation is not amenable to direct scientific calculation. Perhaps the best approach is to review the depths to which excavations for common activities are made. Excavations are routinely made to six to eight feet for public utilities (water and sewer pipes, power lines, telephone lines). Footings for house foundations are often placed at an eight foot depth. In colder climates it is important that water lines and foundations be placed below the frost depth to avoid freezing problems. Graves are also dug to a depth of six feet, or more.

Since digging to or below these depths is common, it can be argued that a significantly greater thickness would be required for isolation. This does not imply that structures will be built on tailings or utility piping run through tailings. It is meant to demonstrate that digging to such depths is frequently practiced. Thus, for an earth cover to provide reasonable isolation it should have a minimum of 3 meters thickness.

3.2.2 Radon Control

Methods for the prevention of radon release into the atmosphere range from simple barriers, such as earth or plastic sheeting, to higher technology means, such as incorporation of the tailings in asphalt or concrete or chemical processing to remove the radon precursors. Radon control methods considered in this analysis are limited to earth covers with the exception of one case involving incorporating the tailings into concrete. Plastic and asphalt covers are not considered since they degrade rapidly in most cases when exposed to the sun. The more advanced methods are not considered except for the concrete fixation alternative since costs are high and not well established, and their effectiveness for radon control is questionable.

Earth placed over tailings slows the movement of radon into the atmosphere by various attenuation processes. When the earth is moist attenuation increases and less radon passes through. Different soils have different attenuation properties. These properties can be described as a half-value-layer (HVL). The HVL is that thickness of cover material (soil) which reduces radon releases to one-half the value from uncovered tailings. Figure 3.1 shows nominal curves for the percentage of radon which would penetrate various thicknesses of different materials with different HVL's. It is emphasized the HVL's are nominal; HVL's will vary significantly at actual sites depending on soil composition, compaction, moisture content, and other factors.

Figure 3.1 is a simplified illustration of radon retention by soils. A complete discussion of radon attenuation is included in Appendix P of the NRC's Generic Environmental Impact Statement (NRC80) and is based on the work of Rogers (Ro81).

From Figure 3.1 it can be seen that 3 meters of sandy soil (HVL = 1.0 meters) will reduce the radon released from tailings about 90 percent. Soils with better attenuation properties would require less thickness to achieve the same reduction. For example, 1 meter of compacted, moist soil (HVL = 0.3 meters) would also reduce the radon release about 90 percent. We conclude from this information that 3 meters of almost any soil can be expected to reduce radon emissions from tailings by at least 90 percent.

3.2.3 Prevention of Spread of Tailings

Methods for control of wind blown and precipitation-carried tailings include earthen and plastic coverings, chemical and asphalt binders which are sprayed on the tailings, grading and contouring to eliminate steep slopes, revegetation, and others. Chemical and asphalt sprays do not last long on tailings and are more suitable for use during the operating time of a mill. For this analysis a combination of grading and contouring slopes, covering with 0.5 meter of earth, landscaping, and continuing maintenance is considered the minimum control for wind blown and precipitation carried tailings.

Methods that provide protection from external gamma radiation require that mass be placed over the source of the penetrating (gamma) radiation. Thus, a plastic sheet has no effect on gamma levels whereas a layer of earth is quite effective in reducing gamma levels.

The amount or thickness of earth that will attenuate the gamma radiation to one-half its initial value is also called a half-value-layer (HVL). As with radon adsorption, the HVL for gamma attenuation depends on soil composition, compaction, moisture content, and other factors. The average HVL of compacted soil is about 0.1 meter. Therefore, a soil thickness of 0.5 meter will reduce the gamma to about 3% of its initial value from the uncovered tailings and 1 meter of soil would reduce it to about 0.1% of its initial value.

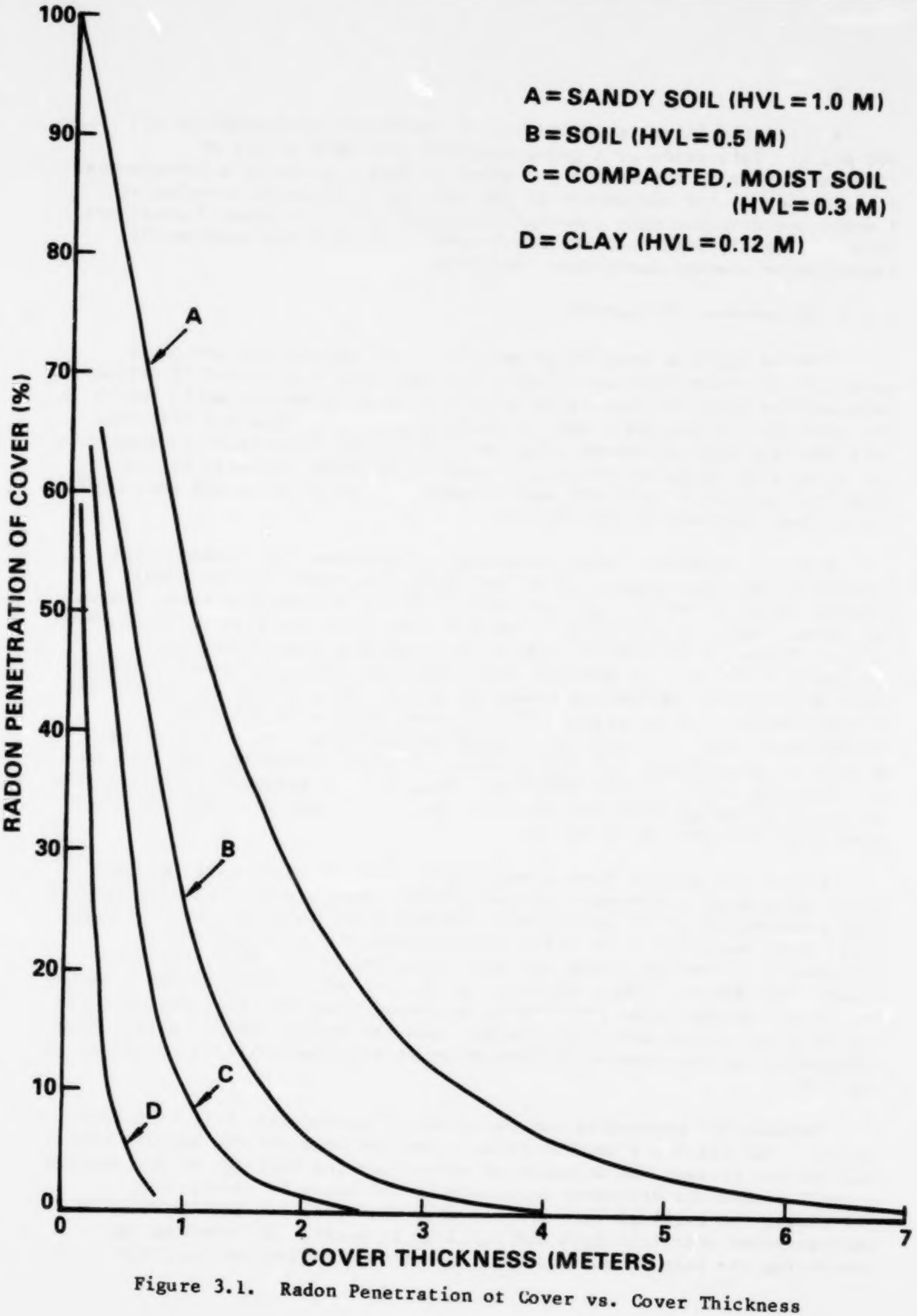

Figure 3.1. Radon Penetration of Cover vs. Cover Thickness

A typical tailings pile may have a radium-226 concentration of 500 pCi/g. This produces a gamma absorbed dose rate in air of 7,000 mrad/year on top of the uncovered tailings, assuming a homogeneous distribution of the radium-226 in the tailings. An earth covering of 1 meter would reduce this absorbed dose rate in air to about 7 mrad/year. This is slightly less than the total gamma dose from the uranium-238 series under average background conditions.

3.2.4 Groundwater Protection

Uranium mills produce large quantities of radioactive and toxic materials in their tailings. These tailings have been stored in unlined impoundments which in many cases were located on permeable soil. Water in the tailings leaches toxic and radioactive materials from the tailings. This leachate with dissolved toxic and radioactive materials can seep into the underlying aquifers, thereby contaminating them. Several of the dissolved materials have very small removal rates in soils and thus can travel some distance in the aquifer.

Arsenic, selenium, lead, manganese, molybdenum, and vanadium are present in varying amounts in the tailings, are highly mobile (small removal rates in soils), and have been found in groundwater above Federal and State limits at distances up to 1.5 miles from tailings piles at seven sites. There are no Federal regulations limiting concentrations in groundwater per se. In general, EPA's National Interim Primary Drinking Water Regulations (NIPDWR) are used to assess the toxicity or health risk of groundwater contamination. This is consistent with the goal established under the SWDA, as amended, regulations: to preserve the quality of groundwater for future uses. Arsenic, selenium, and lead are all assigned limits in the NIPDWR's. Manganese is assigned a limit in the secondary drinking water regulations. Molybdenum may be toxic and has been shown detrimental to cattle.

Corrective actions have already been taken at three tailings pond sites because of groundwater contamination. New, plastic-lined ponds have been constructed at the Cotter Mill, Cannon City, Colorado, and the Dawn Mill, Ford, Washington, to alleviate groundwater contamination. A groundwater cleansing system has been installed at the Homestake Mill, Grants, New Mexico. This involves two rows of wells downgradient from the tailings. Contaminated groundwater is pumped from the first row of wells and recycled; fresh water is injected into the second row of wells. More information on groundwater contamination at existing mills is contained in the EIS.

Methods for preventing contamination of groundwater fall into four groups: (1) placing a barrier between the tailings and the aquifer that will either prevent the movement of water from the tailings to the aquifer or will remove the hazardous materials in the water by adsorption; (2) fixing the tailings into a solid mass that prevents the leaching of the hazardous materials from the tailings by water; (3) covering and contouring the pile to minimize precipitation infiltration into the tailings and to encourage runoff of precipitation; and (4) selecting a site with characteristics that minimize recharge of the aquifer and provides natural adsorption process. Since these are not all available for existing tailings piles, it is important to differentiate between existing tailings piles and new piles either at existing sites or new sites.

The protection afforded by an impermeable barrier such as plastic or an adsorption material such as clay is difficult to estimate, especially over long time periods. Potential groundwater contamination depends on the tailings management practices of the mills, including the amount of water discharged to the tailings pond, the amount of water recycled back to the mill, the years of operation, and other factors. The potential contamination also depends on the amounts of various contaminants in the tailings, the distance between the tailings and the saturated zone (the aquifer), and the geological and hydrological characteristics of the intervening materials.

EPA policy for groundwater protection is that protection is provided during the operational period of a tailings pond by an active water management program that includes a liner on the bottom and sides of the pond. After operations at a tailings pond cease, long term groundwater protection is provided by a cover that is installed over the tailings (EPA82).

For existing mills with existing tailings, groundwater under the pond may or may not be contaminated when these standards become effective. If the groundwater is not contaminated at a site, use of the pond could probably be continued with a continuing monitoring program. If the groundwater is contaminated, corrective actions will be required. In our view, the worst case for corrective action is the construction of a new pond with a liner. The existing pond would be allowed to dry out and then covered. However, it is possible that moving the entire existing pile to a new lined pond could be required to provide adequate groundwater protection.

For new mills, and possibly for future tailings at existing mills, groundwater protection during operation is assumed to be provided by a one meter thick clay liner. A plastic liner would cost about the same as a clay liner. Selection of a site could eliminate the need for a liner, however, if the soil at the site has proper permeability and adsorption characteristics. The total disposal system could also be different for these mill sites if abandoned surface mines or natural land depressions are nearby. Since the liner provides groundwater protection only during the operational period of a tailings pond and since, as explained in Chapter 1, this RIA only addresses the benefits and costs of the proposed disposal standards, we have omitted the cost of the liner in the cost-effectiveness analysis of alternative disposal methods in Chapter 4. In Chapter 5, where we estimate the industry-wide cost of compliance with the standards over a projected time period, we include the cost of a liner since that is a cost that new mills must incur.

3.3 Protection for the Long Term or the Short Term

Mill tailings will be hazardous for a very long time, in the range of hundreds of thousands of years. This period is determined by the radioactive half-life of thorium-230 which is about 75,000 years. Methods providing control for such periods are beyond man's knowledge and experience. In addition, the presence of permanent contaminants in the tailings means that their potential hazards will remain forever.

The goal for long term protection is to provide all reasonable controls for as long a period as the potential hazards remain. Failure of the controls in this case means the loss of isolation from man and the environment. Various control methods are examined in this section.

Failures of long term methods can occur by natural phenomena and through human intrusion, or intervention. Natural phenomena change the landscape through complex interactions of erosion and deposition, flooding, climatic changes, earthquakes, vulcanism, and glaciation. Human intrusion can also take a large number of forms, ranging from common activities such as construction of dwellings and other buildings, to such things as drilling, mining, and dam building. Not all of these items would cause failures of tailings isolation since at some sites these items may actually increase isolation by, for example, depositing additional materials or soil on the tailings. Long term protection will vary considerably from site to site.

3.3.1 Lifetime of Institutional Control

Human institutions can prevent failures of tailings disposal sites. The problem here is that there is no general consensus on the length of time institutions remain effective or reliable. In its proposed criteria for management of radioactive waste (EPA78) which have been withdrawn (EPA81), EPA said that waste disposal plans should limit reliance on institutional controls to 100 years. The issue of how long reliance can be placed on institutional controls cannot be settled by scientific or technical means. Resolution of this issue will be by societal judgment. It is noted, however, that the tailings will remain hazardous for a much longer time than man's recorded history.

Institutional controls are considered active controls in that continuous monitoring and maintenance actions are performed. For example, if a cloud burst causes severe erosion of the disposed tailings cover, the responsible institution would take the corrective actions needed to restore the cover to its original depth. In contrast, a passive control method would provide protection by a thick earth cover that is contoured or graded to promote runoff without erosion. Public health protection in this latter case relies solely on the disposal system. This is the passive control approach. In general, passive controls can be expected to cost more than active controls which are provided by institutions; at least the initial costs of passive controls will probably be greater. However, because technical or passive controls are more reliable and predictable over the long term than institutional or active controls, we conclude that passive controls are the preferred approach. Also because of the long term hazards involved, the question of how long institutional controls will remain viable becomes moot. In all likelihood, institutions established to provide control of the tailings cannot be assumed to last until the tailings hazards are gone.

Failure of institutional controls does not necessarily imply a complete breakdown of societal structure. The more likely situation would be the failure of the individual institution set up to provide control of the tailings through program reductions, reorganizations, or changes in priorities or through the loss of special funding mechanisms by incorporation into general funds, accounting procedures changes, or others. In short, in this context, catastrophies do not have to be assumed to have institutional breakdowns.

3.3.2 Human Intrusion

Human intrusion into tailings becomes a serious problem when the tailings are misused as construction material or fill at occupiable structures, as discussed in subsection 3.2.1. Intrusion can also increase erosion which leads to the eventual spread of tailings and increased risk to man.

The effectiveness of controls in preventing intrusion over long time periods is difficult to evaluate, at best. Probably the worst scenario is the identification of a tailings location as a resource area for construction material by residents of a nearby population center. This could lead to widespread use of tailings around residences, schools and other inhabited structures. Any controls which make a tailings location attractive as a resource area have a potential for promoting misuse. Examples are controls such as fences and covers consisting of small-sized rock. We conclude, therefore, that the disposal site should not be made attractive through the use of easily removed, valuable materials.

Prevention of intrusion by institutional controls can reasonably be expected to vary greatly from site to site. Socio-economic conditions of the area and attitudes of local residents are important factors. These factors will likely determine the length of time a fence remains an effective deterrent to intrusion, even if posted. Annual inspections and maintenance may help to prevent intrusion since people would recognize the site is of continuing interest. Periodic controls such as operation of a sprinkler system for sustaining vegetation may also be an efffective deterrent, for as long as it continues. In any case, active controls can only be counted as effective against intrusion for as long as they are practiced.

Prevention of intrusion for long time periods is more likely to be successful using passive methods. Thick earth covers, for example, can be expected to provide significant protection against intrusion as discussed in subsection 3.2.1. Other passive methods appearing effective against intrusion are deep mine disposal, below grade disposal, solidification in a cement or asphalt admixture, or coverings of a tailings cement mix.

3.3.3 Erosion

All of the surface disposal methods are subject to erosion. Some values for soil erosion rates in the U.S. are given in Table 3.1. These erosion rates are averages and do not mean that the surface is lowered uniformly by this amount. Widely varying rates of erosion, and also of deposition, can be found within any one drainage basin. These rates are most applicable to the below grade surface disposal option. Erosion rates for above grade disposal will be greater. It is also noted that the maximum rate of erosion occurs in areas with about ten inches (25 cm) of rainfall per year (Fo71).

This annual rainfall is typical of the uranium mining and milling areas in the western U.S. Thus the tailings of concern in this standards effort are in areas where maximum rates of erosion occur.

The erosion rates for the Colorado River basin vary between 0.09 and 0.25 meters per 1,000 years. These rates can reasonably be applied to below-grade surface disposal even though wind erosion is not included. Erosion rates for above-grade surface disposal will be greater than below-grade disposal. Wind erosion of these above-grade disposed tailings is expected to be much greater than below-grade depending on the effectiveness of vegetation. Loss of vegetation will increase water erosion. Rock cover will greatly reduce wind erosion. In consideration of these points, and also that erosion rates vary greatly from site to site, it is concluded that 3 meters of soil covering above-grade tailings would provide long term protection for about 1,000 years. The uncertainty in the erosion rates indicates that this soil cover would maintain isolation ranging from a period of a few hundred years to a few thousand years.

3.3.4 Floods

Floods are probably the greatest natural hazard to the tailings piles. Piles can be protected against floods by constructing barriers designed to withstand floods, or by moving them to new sites. Some of the barriers for protecting the piles if they are to be left in place are: grading the piles so that the sides of the piles have gradual slopes; providing protective rock on the slopes (and on the top if needed); and constructing embankments or dikes on the sides of the piles. The exposed sides of the embankments can be protected by rock. For cases where the vulnerability to floods is great enough that disposal in place is considered inadequate, the piles can be moved to less vulnerable sites.

Table 3.1 Soil Erosion Rates in the United States

Erosion Rate (cm/1,000 years)	Measurement Technique	Comments	Reference
6	River load	Average for U.S.	Ju64
4	River load	Columbia River	Ju64
17	River load	Colorado River	Ju64
5	River load	Mississippi River	Ha75
9	River load	Colorado River	Ha75
5	Radioactive dating	Amount of erosion of volcanic extrusion in southern Utah	Ha75
25	River load	Colorado River	Yo75
5	River load	Average for U.S.	Da76
3	River load	Average for North American continent	Pr74

Note: River load refers to erosion rate estimates based on the sediment load (dissolved and detrital particles) carried by rivers.

Flood protection design must be based on very infrequent but high-magnitude floods(1). These floods typically depart significantly from the trend of more frequently observed floods. The interpretation of the data for extreme floods will influence the design of protective measures. Where historical records are of short duration compared to the required longevity of the protection measures, prediction of extreme floods must rely on techniques of geomorphology (Co78). Once the size of flood event to be used has been determined, flood protection can be incorporated into the design of remedial measures.

The "design flood" is the flood adopted as the basis for flood protection for a facility after considering both hydrologic and economic factors. In most areas, the chracteristics of relatively short-term floods, such as the 50-year flood, have been well established and engineers routinely design facilities protected from such events. Where the failure of flood protection systems could result in loss of lives and great property damage, however, a design based on the MPF may be justified. The SPF is often considered an appropriate design basis for facilities where some risk would be tolerable, and the added cost of providing greater protection would be significant. Another consideration is that sometimes the differences between various classes of flood is not very great. Also, the differences in water velocity can be significant and adequate protective systems must be considered site-specifically.

Uncertainties in design specifications and performance may affect the practicality of long-term flood protection systems. The characteristics of long-term recurrence floods, such as the 1000-year flood, are usually much less certain than those of floods that have recurred frequently during historical periods. Furthermore, because of potential damage from erosion and earthquakes, our confidence in the ability of conventional flood protection systems such as dikes and stone reinforcements to withstand a flood declines with time into the future. In view of these combined uncertainties, conservatively designed systems would be required to satisfy very long-term flood protection requirements. Whether for technical or economic reasons, if those requirements could not be satisfied at the present location of a tailings pile, it would have to be moved to a new site where long-term floods are a more manageable threat.

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(1) It is customary to rank the severity of floods in terms of the average time over which floods of a given size or greater may be expected to recur. For example, there will be an average of 5 floods in 1000 years that exceed the "200 year flood." The "maximum probable flood" (MPF), on the other hand, is the largest flood that one would expect to occur in a given region for that climate era. Geomorphic data are best for determining the past rate of occurence of very large floods. When such data are unavailable, the MPF can be estimated from historical records, but such estimates are frequently shown to be inadequate when new severe rainstorms occur.

Another measure of flood severity that is sometimes used as a design criterion is the Standard Project Flood (SPF), which results from the most severe combination of weather and hydrologic conditions that are reasonably characteristic of the region involved, excluding extremely rare combinations.

3.3.5 Time Period Considerations in this Analysis

Based on the above discussions, we found it necessary to choose a time period for evaluating the effectiveness of controls. A relatively short time period of about 100 years was considered first since this was proposed as the limit for reliance on institutional controls (EPA78). We concluded that this time period was of little use since both passive controls and active controls, assuming 100-year institutional contol, maintained their initial effectiveness for the entire period.

A period of about 1,000 years appeared more reasonable for evaluating the effectiveness of controls and was selected. Actually this 1,000 year period can be considered to range from a few hundred years to a few thousand years, depending on individual site characteristics. This selection allows the decision makers to choose from a much broader array of options than just the difference between active and passive controls. This is due to the expected variation of the effectiveness of controls over the longer time period. Also, it does not preclude the choice of the active (institutional control) option.

In general, the effectiveness of controls over time can be rated from best to least as follows:

BEST o Deep geological disposal

o Below-grade surface disposal

o Above-grade surface disposal, entire area covered with thick earth and rock cover

o Above-grade surface disposal, entire area covered with thick earth and slopes covered with rock cover

o Above-grade surface disposal covered with thick earth

LEAST o Above-grade surface disposal with thin earth and maintained

This ranking assumes the tailings pile is located where erosion occurs. If tailings are located where soil deposition is taking place, the assessment will differ significantly as long as deposition continues.

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4. Benefit-Cost Analysis

We examine the costs and benefits of alternative tailings disposal methods in this chapter. The analysis is performed on a model pile basis, done separately for existing tailings piles and new tailings piles. Based on this analysis, we determine the level of control that is optimal for standards development.

4.1 Cost Analysis

Using the classes of control defined in the previous chapter, we select tailings disposal methods which will provide alternative levels of these controls. After selecting the disposal methods, we develop disposal cost estimates for model piles. This section presents a description of each disposal method and its estimated cost. The reader should refer to the EIS for a detailed explanation on the development of the model pile cost estimates.

Disposal methods were selected for both existing and new tailings piles. Seven different methods were considered for both existing tailings (designated ET1 through ET7) and new tailings piles (designated NT1 through NT7). Table 4.1 lists all the disposal methods according to various characteristics including the grade of the slope, thickness of earth cover, use of rock cover, below-grade or above-grade, and use of liner.

For existing tailings, we developed the disposal cost estimates for three model-sized piles. As of January 1980, there were 23 licensed uranium mills with tailings piles. An analysis of these piles indicates that they vary widely in size and, thus, control costs would vary greatly. Consequently, we grouped the existing piles into model piles as follows:

a. 2 million ton pile on 48 ha with an average depth of 2.37m
No. of piles in this group = 10
Average tons per pile = 1.8 million
(Range = 1.0 to 2.8 million tons)
Average area covered = 48 ha
(Range = 13.8 to 98.4 ha)

b. 7 million ton pile on 56 ha with an average depth of 7.72 m
No. of piles in this group = 10
Average tons per pile = 6.85 million
(Range = 4.2 to 11.0 million tons)
Average area covered = 56 ha
(Range = 31.1 to 86.6 ha)

c. 20 million ton pile on 98 ha with an average depth of 12.85 m
No. of piles in this group = 3
Average tons per pile = 19.9 million
(Range = 17.1 to 24.6 million tons)
Average area covered = 98 ha
(Range = 82.6 to 106.2 ha)

Table 4.1. Characteristics of Tailings Disposal Methods

Disposal Method	Slope	Earth Cover Thickness(m)	Rock Cover	Put Below Grade	Liner	Cement Fixation
Existing Tailings Piles						
ET1	5:1	.5(a)				
ET2	5:1	1	slopes			
ET3	5:1	3	slopes			
ET4	8:1	3	slopes			
ET5	8:1	5	slopes			
ET6	5:1	1	total area			
ET7		3		X	X	
New Tailings Piles						
NT1	No treatment (Tailings Pond Only)					
NT2	5:1	.5[a]			X	
NT3	5:1	1	slopes		X	
NT4	5:1	3	slopes		X	
NT5		3		X	X	
NT6	8:1	5	slopes		X	
NT7				X		X

(a) Assumes maintenance for 100 years.

For new tailings piles, we developed cost estimates for a single model pile. This model pile is based on the quantity of tailings generated by NRC's model mill in their GEIS (NRC80). The NRC model mill has an ore-processing capacity of 1,800 MT per day. The ore grade is expected to average 0.1% uranium and the uranium recovery efficiency is assumed at 93%. The mill is operated 310 days per year (i.e., 85 percent capacity utilization rate) and the average annual production is 580 MT yellowcake which is 90% U_3O_8. The tailings will be generated at a rate of 1,800 MT per day, or 558 thousand MT per year, or 8.4 million MT during the assumed 15 year operating period of the mill. The tailings cover an area of 80 ha with earth embankments around the tailings bringing the total area to 100 ha. The depth of tailings is about 8 meters.

Each of the disposal methods is described below.

Method ET1

The sides of the square tailings pile are graded to a 5:1 (H:V) slope. The entire area is then covered with 0.5 meter of earth obtained nearby. A 6-feet high, 6-gage aluminum chain link fence is placed around the exclusionary zone, which is assumed to be 0.5 km from all sides of the pile. The covered pile is landscaped assuming that suitable loam or topsoil is available onsite. The borrow pit is reclaimed. The site is maintained for 100 years by irrigation of the vegetative cover and inspection and repair of the earth cover and fence.

Method ET2

The sides of the tailings piles are graded to 5:1 (H:V) slope. The tailings are covered with 1 meter of earth obtained nearby and the slopes are covered with 0.5 meter of rock cover. There is no maintenance and inspection of the pile. The top of the disposed tailings area (that part not covered with rock) is landscaped. A fence is installed to form an exclusion area 0.5 km wide all around the disposed tailings. The borrow pit is reclaimed.

Method ET3

The sides of the tailings piles are graded to a 5:1 (H:V) slope. The entire tailings area is covered with 3 meters of earth obtained nearby. After covering, the slopes are covered with rock and the tops of the piles are landscaped. No fence is necessary. The borrow pit is reclaimed.

Method ET4

The sides of the tailings piles are graded to a 8:1 (H:V) slope and the entire area is covered with 3 meters of earth obtained nearby. The slopes are covered with 0.5-meter rock cover and the tops of the piles are landscaped. No fence is needed. The borrow pit is reclaimed.

Method ET5

The edges of the tailings piles are graded to a slope of 8:1 (H:V). The entire area is then covered with 5 meters of earth obtained nearby. The slopes are covered with 0.5-meter thick rock cover and the tops of the piles are landscaped. No fence is necessary. The borrow pit is reclaimed.

Method ET6

The sides of the tailings piles are graded to a 5:1 (H:V) slope. The entire area is then covered with 1 meter of earth obtained nearby. The entire pile is then covered with 0.5 meters of rock. A fence is installed to form an exclusion area 0.5 km wide all around the disposed tailings. The borrow pit is reclaimed.

Method ET7

This disposal method provides for below-surface level disposal of the tailings with a 1-meter clay liner below the tailings and a 3-meter earth cover over the tailings. For the 2 million ton pile, a 366 meter square pit is excavated to a 12 meter depth adjacent to the pile. The bottom of the pit is assumed to be above the groundwater table. The pit is lined with 1 meter of clay which is assumed to be purchased and hauled 3.2 km. The tailings are moved into the pit with scrapers after which they are covered with 3 meters of the excavated earth. The disposal area is landscaped.

The disposal pit for the 7 million ton pile is 614 meters square and 15 meters deep, while the 20 million ton pile is 1,047 meters square and also 15 meters deep. Both are assumed to be above the groundwater table. Because of the large sizes, we assumed that the tailings are hauled by trucks for an average off-road distance of 3.2 km. The disposal method and landscaping is similar to the 2 million ton case.

Method NT1

This method is the same as the base case in the NRC GEIS analysis (NRC80). An initial basin would be formed by building low earthen embankments on the four sides of a square. The mill tailings would be slurried into the basin and as the basin filled, the coarse fraction of the tailings (sands) would be used to raise and broaden the embankments. When the mill ceases operations, no specific control measures for disposal would be used. The cost for this option consists only of the preparation of the initial basin.

Method NT2

This method is similar to ET1 since both use a thin earth cover on the tailings and rely on institutional controls for 100 years to prevent misuse. A pit is excavated close to the mill and measures 930 meters square and 2 meters deep. Embankments are constructed along each side, 947 meters long, 10 meters high, and 13 meters wide at the top. The pit is lined with 1 meter of clay obtained locally. Tailings are pumped directly into the pit during operation of the mill. It is assumed water from the pond will be recycled to the mill, thereby negating the need for an evaporation pond.

At the end of mill life, the embankments are excavated and placed on top of the tailings providing a 0.5 meter earthen cover. The slopes of the covered tailings are graded to 5:1 (H:V). The entire area is landscaped. A fence is placed around the disposal area and provides a 0.5 km exclusion zone. The site is maintained for 100 years by irrigation of the vegetative cover and inspection and repair of the earth cover and fence.

Method NT3

This method is similar to ET2 since both use a 1-meter earth cover and a 0.5-meter rock cover on the slopes. A pit is prepared and used identical to that described for method NT2.

At the end of mill life, the embankments are excavated and placed on top of the tailings providing a 1-meter earthen cover. The slopes of the disposed tailings are graded to 5:1 (H:V) and then covered with 0.5 meters of rock. The top of the disposed tailings area is landscaped. A fence is contructed at a distance of 0.5 km from the edge of the disposed tailings all around the site.

Method NT4

This method is similar to ET3 since both use a 3-meter earth cover and a 0.5-meter rock cover on the slopes. A pit is excavated, prepared, and used identical to that described for method NT2.

At the end of mill life, the embankments are excavated and placed on top of the tailings. Additional earth cover is obtained from a nearby borrow pit so that the final earth cover over the tailings is 3 meters deep. The slopes of the covered tailings are graded to 5:1 (H:V) and are covered with a 0.5-meter rock cover. The top of the earth-covered tailings is landscaped. The borrow pit is reclaimed.

Method NT5

This method is similar to the staged or phased disposal method described in the NRC's GEIS (NRC80). This method uses 6 pits of 300 meters square and 13 meters deep. Two pits are constructed initially and lined with 1 meter of clay. Tailings are pumped to the first pit until it is full and then pumped to the second pit. When the first pit is sufficiently dry, the third or fourth pit is excavated, and the excavated earth from this pit is used to cover the first pit to a depth of 3 meters, up to the original ground contour. This process continues sequentially until the end of mill life. An evaporation pond is needed in this method.

At the end of mill life, there will likely be 4 completed pits, which are covered with 3 meters of earth to the original ground contour, and 2 uncovered pits. When sufficiently dry these last 2 pits are covered with 3 meters of excavated earth to the original ground contour. The disposed tailings area is landscaped. The areas covered by the evaporation pond and excess excavated earth are restored.

Method NT6

This method is similar to ET5 since both use a 5-meter earth cover and a 0.5-meter rock cover on the slopes. A pit is excavated, prepared, and used in the same manner as that described for method NT2.

At the end of mill life, the embankments are excavated and placed on top of the tailings. Additional earth cover is obtained from a nearby borrow pit so that the final earth cover over the tailings is 5 meters deep. The slopes of the covered tailings are graded to 8:1 (H:V) and are covered with a 0.5-meter rock cover. The top of the earth-covered tailings is landscaped. The borrow pit is reclaimed.

Method NT7

This method is the same as alternative 7 in the NRC GEIS (NRC80). The tailings are pumped to the edge of a depleted mine pit where the sands (coarse fraction) and slimes (fines fraction) are separated. The sands are washed, dried, and deposited in the mine pit. The slimes are partially dried, mixed with cement, and deposited in the mine pit where the cement/fines slurry would harden.

The total cost and unit cost for each disposal method and model pile are displayed in Table 4.2.

4.2 Benefits Analysis

The benefits of each disposal method are the degree to which each of the goals of the standards is achieved. All of the benefits are health-related. While some can be quantified in terms of health risk, others cannot. The benefit we are best able to estimate is the number of lung cancer deaths averted by radon control. We can estimate the reduction in radon emissions resulting from the placement of earth covers and then translate the radon emissions reduction into lung cancer deaths averted by using models for radon inhalation. The other benefits from tailings disposal are not quantifiable since we do not know what would take place in the absence of the environmental control. Consequently, the incremental benefit of the control cannot be estimated. While we cannot quantify these benefits, we nevertheless can qualitatively discuss the likelihood that these control methods may provide protection and the length of time over which they are expected to remain effective. Several measures of the benefits of control of mill tailings have been developed. The benefits provided by each disposal method are discussed in-depth in the EIS which accompanies this RIA. Table 4.3 summarizes these benefit measures.

Table 4.2. Disposal Cost Summary for Model Piles(a)

Disposal Method	Total Cost (Millions of 1981 $)			Unit Cost ($/MT of Tailings)		
Existing Tailings:	Model Pile Size (MT)			Model Pile Size (MT)		
	2	7	20	2	7	20
ET1	3.9	5.7	11.1	1.96	0.81	0.56
ET2	3.8	7.0	14.4	1.90	0.99	0.72
ET3	6.9	11.4	22.3	3.47	1.62	1.12
ET4	7.6	13.9	29.2	3.81	1.99	1.46
ET5	11.9	19.9	40.6	5.97	2.84	2.03
ET6	12.8	17.4	32.5	6.40	2.48	1.63
ET7	12.3	43.7	126.9	6.16	6.24	6.35
	(10.4)	(38.4)	(111.7)	(5.23)	(5.49)	(5.58)
New Tailings:	Model Pile Size (MT)			Model Pile Size (MT)		
	8.4			8.4		
NT1	1.2			0.14		
NT2	25.8 (13.8)			3.07 (1.64)		
NT3	27.4 (15.4)			3.26 (1.83)		
NT4	33.5 (21.5)			3.99 (2.56)		
NT5	35.8 (27.0)			4.27 (3.21)		
NT6	43.9 (31.9)			5.23 (3.80)		
NT7	91.2			10.85		

(a) Cost estimates in parentheses exclude the cost of a liner which provides groundwater protection during the operational phase of a tailings pond.

Table 4.3. Benefits of Controlling Uranium Mill Tailings

Disposal Method	Stabilization			Radon Control		Water Protection
	Chance of Misuse	Misuse Inhibited (years)	Erosion Avoided (years)	Deaths Avoided Per Century, Per Pile[a]	Maximum Risk[b] of Lung Cancer (% Reduction)	Groundwater Protected (y)
NEW TAILINGS						
NT1	Most likely	0	0	0	4 in 10^2 (0%)	0
NT2	More likely	100	hundred	6-19	2 in 10^2 (50%)	100
NT3	Likely	100's	hundreds	10-31	1 in 10^2 (80%)	100's
NT4	Unlikely	1,000	thousands	12-37	2 in 10^3 (95%)	1,000
NT5	Unlikely	> 1,000	many thousands	12-37	2 in 10^3 (95%)	> 1,000
NT6	Very unlikely	> 1,000	many thousands	13-39	1 in 10^4 (99%)	> 1,000
NT7	Very unlikely	> 1,000	many thousands	12-37	2 in 10^3 (95%)	> 1,000
EXISTING TAILINGS						
ET1	More likely	100	hundreds	6-19	2 in 10^2 (50%)	100
ET2	Likely	100's	thousands	10-31	1 in 10^2 (80%)	100's
ET3	Unlikely	1,000	thousands	12-37	2 in 10^3 (95%)	1,000
ET4	Unlikely	1,000	thousands	12-37	2 in 10^3 (95%)	1,000
ET5	Very unlikely	> 1,000	many thousands	13-39	1 in 10^4 (99%)	> 1,000
ET6	Unlikely	> 1,000	many thousands	10-31	1 in 10^2 (80%)	0
ET7	Unlikely	> 1,000	many thousands	12-37	2 in 10^3 (95%)	> 1,000

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[a] New Tailings. The total lung cancer deaths attributable to radon from the model tailings pile are estimated as 13 per century from a remote site and 39 from a rural site, if no disposal actions are taken.

Existing Tailings. The total lung cancer deaths attributable to radon from the model existing piles are also 13 per century from a remote site and 39 from a rural site, if no disposal actions are taken. The total lung cancer deaths from uncontrolled tailings existing at the 23 sites as of January 1980 are estimated to be 450 per century.

Total lung cancer deaths attributable to radon from uncontrolled existing tailings plus future tailings estimated to be generated through the year 2000 under the baseline demand projection are estimated to be about 1400 per century.

[b] Lifetime risk of fatal cancer to an individual assumed to be living 600 meters from center of a tailings pile.

The benefits of prevention of misuse are expressed in terms of the likelihood that misuse might occur and the number of years over which the control is expected to inhibit misuse. The likelihood of misuse during the period of effectiveness of these methods ranges from most likely for the no control case (NT1) to very unlikely for the tailings solidification method (NT7) and the 5-meter earth cover (NT6 and ET5). The number of years of prevention of misuse ranges from zero for the no control case (method NT1) to greater than 1000 years for the methods having tailings solidification (NT7), below-grade disposal with a 3-meter earth cover (NT5 and ET7), a 5-meter earth cover (NT6 and ET5), or rock cover over the entire tailings pile (ET6).

The benefit of prevention of surface spread of tailings is expressed on the basis of the number of years over which erosion of the tailings is prevented. Erosion prevention is estimated to range from 100 years for the one-half-meter earth cover to many thousands of years for the 3- and 5-meter earth covers.

The benefits of radon control are estimated in terms of the total number of lung cancer deaths which are avoided and the maximum lifetime lung cancer risk to an individual living close to the pile. The total lung cancer death rate from radon emissions from the model piles at active mill sites is estimated for each model pile to be 13 to 39 deaths per century if no controls are used. This range in estimated deaths corresponds to two different population distributions around the pile, referred to as "remote" and "rural" sites. Methods having 3-meter earth covers would reduce this rate to about 1 to 2 deaths per century for each model pile. The benefit from a 5-meter earth cover would be the virtual elimination of the radon risk. The lifetime risk to the individual living 600 meters from the center of the pile is estimated to be 4 in 100 for an uncontrolled tailings pile. This risk is reduced to 2 in 1000 for a 3-meter earth cover and 1 in 10,000 for a 5-meter cover.

The benefit of protecting groundwater is the preservation of its existing quality for future uses. The great majority of the potential contamination of groundwater is the result of process fluids which are discharged to the tailings pond during the operating life of the mill. This potential contamination can be prevented by either the installation of a liner (before tailings are generated) or the selection of a disposal site with favorable geological and hydrological characteristics. Groundwater contamination may also occur after disposal of tailings if precipitation infiltrates the tailings and then enters an aquifer. As discussed in Chapter 3, groundwater protection after disposal is provided by the earthen cover placed over the tailings. The benefit of groundwater protection is measured by the number of years over which the cover is expected to prevent contamination. This benefit is estimated to range from 100 years for the active maintenance disposal methods (NT2 and ET1) to greater than 1000 years for the tailings solidification method (NT7), below-grade disposal with a 3-meter cover (NT5 and ET7), and the 5-meter cover methods (NT6 and ET5). Groundwater protection during the operational phase of a tailings pond is covered by the proposed operations standards and, therefore, is not addressed in this benefits analysis.

Since the radon control benefits are the only benefits that we can quantify, we have compared the disposal cost for each method to the number of deaths avoided to gain some insight as to the level of benefits associated with control expenditures. Since radon control is just one of several benefits to be realized from control of tailings, the results of this limited benefit-cost comparison can be viewed as determining the minimum level of benefits which is obtainable. Table 4.4 shows for each disposal method deaths avoided per century and the tailings disposal cost, both estimated on a model pile basis. A range in avoided deaths is presented which reflects the estimates for a remote site (low estimate) and a rural site (high estimate). This benefit-cost comparison is done for the model new tailings pile and medium-sized model existing tailings pile.

The disposal methods are listed in ascending order of the number of deaths avoided by radon control, and both the average and incremental cost per death avoided is shown for each method. The average cost is simply the ratio of the disposal cost to the total number of deaths avoided. The incremental cost is the ratio of the change in disposal cost to the change in deaths avoided from the previous disposal method. EPA has estimated from studies of market compensation for small risks that people would be willing to pay from 0.3 to 2.5 million dollars to save a life (EPA82). Upon examining the average cost estimates in Table 4.4, we see that all disposal methods, except ET7 and NT7 for remote sites, fall within the upper limit of 2.5 million. A more appropriate measure of the benefit-cost tradeoffs of the alternative disposal methods is the incremental changes in costs and benefits. The estimates of incremental cost per death avoided by radon control indicate that controls as restrictive as method ET3 for existing tailings may be justified since they fall below the $2.5 million upper limit. For new tailings, the incremental cost for method NT4 at rural sites is within the range of the value of life studies, while at remote sites the cost is higher than the upper limit. Beyond ET3 and NT4, the incremental cost increases significantly.

There are several limitations to this type of benefit-cost comparison. A major limitation is the determination of the time period over which the deaths avoided should be estimated. Since the mill tailings remain hazardous for thousands of years, the benefits of control are also realized for thousands of years or as long as the control method remains effective. The computational problems of estimating cost per death avoided are evident. The longer the time period considered, the more favorable the ratio becomes. A related issue is how the future stream of benefits should be related to costs which are incurred all at once at time of disposal. Should the present value of benefits and costs be used or not? Another limitation of this type of analysis is that the accepted range of the value of a statistical life is based on people's estimates of the value of reductions in relatively small risk activities and not a direct estimate of the value of life. Therefore, the

Table 4.4. Radon Control Benefits Versus Disposal Cost

Disposal Method	Deaths Avoided Per Century	Model Pile Disposal Costs[a] (10^6 1981 $)	Average Cost Per Death Avoided (10^6 1981 $)	Incremental Cost Per Death Avoided (10^6 1981 $)
Existing Tailings (7 million MT pile):				
No disposal	0	0	-	-
ET1	6-19	5.7	.3-1.0	.3-1.0
ET2	10-31	7.0	.2-.7	.1-.3
ET6	10-31	17.4	.6-1.7	(b)
ET3	12-37	11.4	.3-1.0	.7-2.2
ET4	12-37	13.9	.4-1.2	(b)
ET7	12-37	43.7	1.2-3.6	(b)
ET5	13-39	19.9	.5-1.5	4.3-8.5
New Tailings:				
NT1	0	1.2	-	-
NT2	6-19	13.8	.7-2.3	.7-2.3
NT3	10-31	15.4	.5-1.5	.1-.4
NT4	12-37	21.5	.6-1.8	1.0-3.1
NT5	12-37	27.0	.7-2.3	(b)
NT7	12-37	91.2	2.5-7.6	(b)
NT6	13-39	31.9	.8-2.5	5.2-10.4

(a)Excludes cost of liner for groundwater protection during operational phase of mill.

(b)No measurable incremental radon health benefit from previous method, but other incremental benefits, such as prevention of misuse, are realized.

application of this estimated range of life valuation to regulations concerning human health effects may be questionable. Another limitation is the high degree of uncertainty in the radon death estimates. The EIS explains the estimation procedure for the deaths avoided and the sources of uncertainty. Lastly, this benefit-cost comparison only covers one category of benefits and, therefore, ignores the attainment of other benefits for the same expenditure. The incorporation of all of the benefits into an analytical benefit-cost framework is the subject of the rest of this chapter.

Even if each of the benefits could be quantified in some manner, there still would be no common numerical basis for expressing each estimation. To perform a benefit-cost analysis of disposal methods, there is a need for an expression of the combined benefit of each method. While we cannot quantify these benefits, we believe that we can quantify, on a relative basis, the effectiveness of disposal methods in providing each of the classes of control. This quantification of the effectiveness of disposal methods can serve as a gauge for the benefits estimation. To meet this need, we have developed an effectiveness index which provides a numerical measure of the overall effectiveness (or benefit) of each disposal method.

The formulation of the effectiveness index depends on (1) the relative effectiveness of disposal methods in achieving each class of control; and (2) judgmental weighting factors for each control class. For each tailings disposal method (see Table 4.1), a rating from zero to ten is assigned for each of the control classes. The rating corresponds to the degree of effectiveness of the disposal method in providing the control; zero represents no effectiveness, while ten stands for 100 percent effectiveness. Independently, each of the control classes must be assigned a weighting factor. This requires a judgment on the relative importance of each of the goals of the standards when compared with one another. After the numerical weights are established, a weighted average effectiveness index for each disposal method is calculated.

This estimation procedure yields a single measure of the overall benefit of each disposal method. The remainder of this section explains in detail how the effectiveness index is calculated and describes the assumptions upon which it is based.

The disposal methods are rated for their likelihood of effectively providing each of the classes of control for approximately 1000 years duration. Due to the long time period, we have relied heavily on our judgment in developing these ratings. Much of this judgment has already been discussed in Chapter 3. Although these ratings may be questioned when viewed in an absolute sense, we feel that they have more validity when viewed in a relative sense. For example, it is extremely difficult to estimate how effective a 1-meter earth cover is in preventing misuse for 1000 years. However, we can be certain that a 3-meter earth cover has a greater likelihood of preventing misuse than a 1-meter cover. It is in this relative sense that the effectiveness index is used in this RIA.

Table 4.5 presents the effectiveness ratings for each disposal method and class of control.

Prevention of Misuse

The ratings for prevention of misuse are arbitrary. The basis for the relative rankings of the disposal methods in providing long- term isolation was discussed in Chapter 3. We feel that a minimum of a 3-meter earth cover or a substantial rock cover is necessary to isolate the tailings for 1000 years. Therefore, we rated the methods with a 1-meter earth cover and rocks on the slopes only as providing only 20 percent effectiveness. The one-half meter earth cover with 100-year maintenance was given a 1 since, after the maintenance stops, the thin earth cover will not be effective in preventing misuse over the next 900 years.

The highest rated methods were below-grade disposal with a three-meter earth cover and cement fixation, both assigned a rating of 9. The 5-meter earth cover with rocks on the slopes was rated just slightly lower with an 8. Next, the methods using a 3-meter earth cover with rocks on the slope were assigned either a 7 or a 6 depending on whether the slope was 8:1 or 5:1. We also feel that 1 meter of earth with rock cover over the entire area will provide a reasonable degree of isolation so that this method was also assigned a 6.

Radon Control

The effectiveness ratings for radon control are based primarily on the attenuation characteristics shown for different soil types in Figure 3.1. Based on these data and allowing for some erosion and potential disruption to parts of the cover material over the 1000-year time period, we assigned an 8 to the 5-meter earth cover which is accompanied by rock cover on the slopes. We also assigned an 8 to the case of a 3-meter earth cover and below-grade disposal since we feel that disposal below grade will maintain the integrity of the earth cover for a longer time period than rock cover on the slopes. Therefore, the 2-meter difference in cover thickness is offset by the better longevity capability of below-grade disposal. For the same reason, the 3-meter earth cover with rock cover on the slopes was assigned a slightly lower rating, 7, than the 3-meter, below-grade disposal method. Disposal with a 1-meter earth cover with rock cover over the entire pile was assigned a 4 since this rock cover should keep most of the earth in place for the duration of the time period. The 1-meter earth cover with rock cover on the slopes was assigned a 3. The case of one-half meter of earth accompanied by 100-year maintenance was given a rating of 1 since, after the maintenance stops, we assumed that the earth cover (with no rock cover) would not last for an additional 900 years due to erosion and other potential disruptions. We assigned a 9 to the new tailings disposal method which includes cement fixation of the tailings.

Table 4.5. Effectiveness Index for Disposal Methods by Class of Control

Disposal Method	Prevent Misuse	Radon Control	Prevent Spread of Tailings	Groundwater Protection	Weighted Average[a]
ET1	1	1	1	1	1.0
ET2	2	3	6	2	2.7
ET3	6	7	9	7	6.7
ET4	7	7	9	7	7.3
ET5	8	8	10	9	8.5
ET6	6	4	10	1	5.5
ET7	9	8	10	7	8.7
NT1	0	0	0	0	0
NT2	1	1	1	1	1.0
NT3	2	3	6	2	2.7
NT4	6	7	9	7	6.7
NT5	9	8	10	7	8.7
NT6	8	8	10	9	8.5
NT7	9	9	10	9	9.2

(a)The weights for this average are as follows:

I. Prevention of misuse - 60 percent
II. Radon control - 5 percent
III. Prevention of surface spread of tailings - 15 percent
IV. Groundwater protection - 20 percent

Prevention of Surface Spread of Tailings

As discussed in Section 3.2, the spread of tailings by wind, precipitation and surface water is effectively eliminated by 1 meter of earth. Also, a 1-meter earth cover reduces external gamma radiation to background levels, or to levels caused by the radioactive materials in the cover soil itself. Therefore, disposal methods which are expected to maintain at least a 1-meter cover for 1000 years were rated either a 9 or 10. Below-grade disposal with a 3-meter earth cover, five meters of earth with rock cover on the slopes, cement fixation of tailings, and a 1-meter earth cover with rocks over the entire area were assigned a 10. The methods with a 3-meter earth cover and rocks on the slopes were rated 9. The case of 1 meter of earth, rock cover on the slopes received a 6, while the 100-year maintenance method was rated a 1.

Groundwater Protection

Protection of groundwater from contamination by the process fluids during mill operation is provided by placing a clay or plastic liner between the tailings and the ground surface. Selection of a disposal site in clay soils and at a substantial distance from aquifers can also provide groundwater protection and eliminates the need for a liner. Other methods include promoting runoff of precipitation and minimizing drainage into a tailings pile. However, these other methods are highly dependent on the site characteristics.

After mill operation, groundwater can still be contaminated by precipitation entering the tailings pile and then reaching the groundwater. We estimate that the potential groundwater contamination occuring after mill operation is very slight in comparison to the potential contamination due to the discharge of process fluids. Nevertheless, a thick earthen cover is required to prevent any additional groundwater contamination.

Since we are only concerned in this RIA with groundwater protection after disposal, the effectiveness ratings are based on the thickness of the earth cover. The 5-meter earth cover and the tailings solidification methods received a rating of 9, while each of the methods using a 3-meter cover were assigned a 7. Disposal below-grade may maintain the integrity of the earth cover longer than above-grade disposal, but water has a more likely chance of penetrating a pile below-grade than one above-grade which has been designed for run-off. We have assumed that these factors offset each other and, therefore, result in the same ratings for each method. The 1-meter cover with rocks on the slopes was assigned a 2, while the 1-meter earth cover with rocks over the entire tailings pile received a 1 since the rock cover would prevent any moisture from evaporating and would thus be counter-productive. The active maintenance methods were also rated a 1.

Benefit Weighting Factors

The selection of the weighting factors for the classes of controls is required in order to express a measure of the overall benefit. If all of the health-related objectives of these standards could be stated on a quantitative risk basis, then combining the estimation of individual benefits would be a straight-forward summation of the individual benefits. However, as stated earlier in this chapter, we cannot express each of the benefits in health-risk terms. Therefore, we need an alternative means of combining the benefits.

For determining the benefit weighting factors, we have relied on the judgment of the EPA technical staff regarding the relative importance of each class of control. Members of the staff who are knowledgeable about the health risks from uranium mill tailings were polled for their opinions on this subject. They were asked independently to assign numerical weights (totalling 100 percent) to each of the four control classes which reflect their views on the relative importance of each goal. The average of the five percentage distributions was calculated and is shown below:

I. Prevention of misuse - 60 percent

II. Radon control - 5 percent

III. Prevention of surface spread of tailings - 15 percent

IV. Groundwater protection - 20 percent

In the public comment period, we hope to incorporate a broader base of opinion from other government agencies, industry and the general public, as to the prioritization of the goals of the standards. If necessary, these weighting factors will be revised to reflect such opinions. These weights support the Agency's view that the primary objective of the standards is to isolate the tailings to prevent their misuse. Two alternative weighting schemes which are very different than the one displayed above were also devised and are evaluated in the sensitivity analysis presented in Section 4.3.

4.3 Cost-Effectiveness Analysis

In a broad sense, the purpose in performing a benefit-cost analysis is to direct the allocation of resources in the most efficient way possible. In applying benefit-cost analysis to government regulations, the intent is to ensure that, first, the benefits attributed to the regulation outweigh the costs, and, second, that the proposed form of the regulation yields the greatest net benefit when compared to other regulatory alternatives. Underlying the analysis is the assumption that the benefits can be expressed on a comparable, monetary basis with the costs. In the development of environmental regulations, benefit- cost analysis is often rejected because this monetization of benefits is not feasible. In this section, we employ a modified form of benefit-cost analysis, cost-effectiveness analysis, to determine a level of control for tailings disposal that represents a reasonable balancing of costs and benefits. We do not monetize the benefits, but we do quantify the overall benefit or effectiveness of each disposal method and relate this measure to the total costs in a systematic manner.

The total cost and effectiveness index for each disposal method is presented in Table 4.6 for existing tailings piles and in Table 4.7 for new tailings piles. As explained earlier, the liner costs were excluded from the disposal cost estimates used in this analysis since the liner requirement is due to the operations standards and is not part of the tailings disposal system. Similarly, the benefits provided by a liner during the operational phase of the tailings pond have not been considered in this cost-effectiveness analysis. We have only considered the effectiveness of the cover in providing groundwater protection after disposal. The disposal methods are listed in order of ascending value of the effectiveness index. These same data are presented graphically in Figures 4.1 through 4.4.

Upon examining these estimates, it is apparent that some disposal methods are totally dominated by others in that they have both a lower (or equal) effectiveness rating and higher cost. Clearly, one would not select such a method (on the grounds of benefit-cost analysis) when there are others that would provide greater or equal benefit at lower cost. Therefore, these methods are eliminated from further consideration. These methods are represented by the points located below the curves in Figures 4.1 through 4.3.

In Tables 4.6 and 4.7, we have calculated the average and incremental costs of each disposal method. The average cost is the ratio of the total cost to the effectiveness index. The incremental cost is the ratio of change in cost from the preceding method to the change in the effectiveness index. The incremental cost measure is the cost of the incremental benefit that each method provides. According to economic theory, we would select the method in which the marginal cost equals the value of the marginal benefit. However, as stated above, we cannot make this determination since the monetary value of the effectiveness index cannot be estimated. Despite the inability to determine the point where marginal cost equals marginal benefit, these data can be used to determine a reasonable level of control.

For the 2 million MT model existing tailings pile, the incremental cost decreases from ET2 to ET3, increases by 50 percent from ET3 to ET4, and then nearly doubles from ET4 to ET7. Disposal methods ET1, ET6, and ET5 are eliminated from consideration since they are dominated by other methods. Therefore, controls as far as ET4 appear reasonable, while beyond this point it is uncertain. For the 7 million MT pile, the

Table 4.6. Cost-Effectiveness of Disposal Methods, Existing Tailings

Disposal Method	Effectiveness Index	Total Cost (10^6 1981 $)	Average Cost	Incremental Cost
2 million MT Pile				
No disposal	0	0	---	---
ET1	1.0	3.9	Eliminated from consideration	
ET2	2.7	3.8	1.4	1.4
ET6	5.5	12.8	Eliminated from consideration	
ET3	6.7	6.9	1.0	.8
ET4	7.3	7.6	1.0	1.2
ET5	8.5	11.9	Eliminated from consideration	
ET7	8.7	10.4	1.2	2.0
7 million MT Pile				
No disposal	0	0	---	---
ET1	1.0	5.7	5.7	5.7
ET2	2.7	7.0	2.6	.7
ET6	5.5	17.4	Eliminated from consideration	
ET3	6.7	11.4	1.7	1.1
ET4	7.3	13.9	1.9	4.2
ET5	8.5	19.9	2.3	5.0
ET7	8.7	38.4	4.4	92.5
20 million MT Pile				
No disposal	0	0	---	---
ET1	1.0	11.1	11.1	11.1
ET2	2.7	14.4	5.3	1.9
ET6	5.5	32.5	Eliminated from consideration	
ET3	6.7	22.3	3.3	2.0
ET4	7.3	29.2	4.0	11.5
ET5	8.5	40.6	4.8	9.5
ET7	8.7	111.7	12.8	355.5

Table 4.7. Cost-Effectiveness of Disposal Methods, New Tailings

Disposal Method	Effectiveness Index	Total Cost (10^6 1981 \$)	Average Cost	Incremental Cost
NT1	0	1.2	----	-----
NT2	1.0	13.8	13.8	12.6
NT3	2.7	15.4	5.7	.9
NT4	6.7	21.5	3.2	1.5
NT6	8.5	31.9	Eliminated from consideration	
NT5	8.7	27.0	3.1	2.8
NT7	9.2	91.2	9.9	128.4

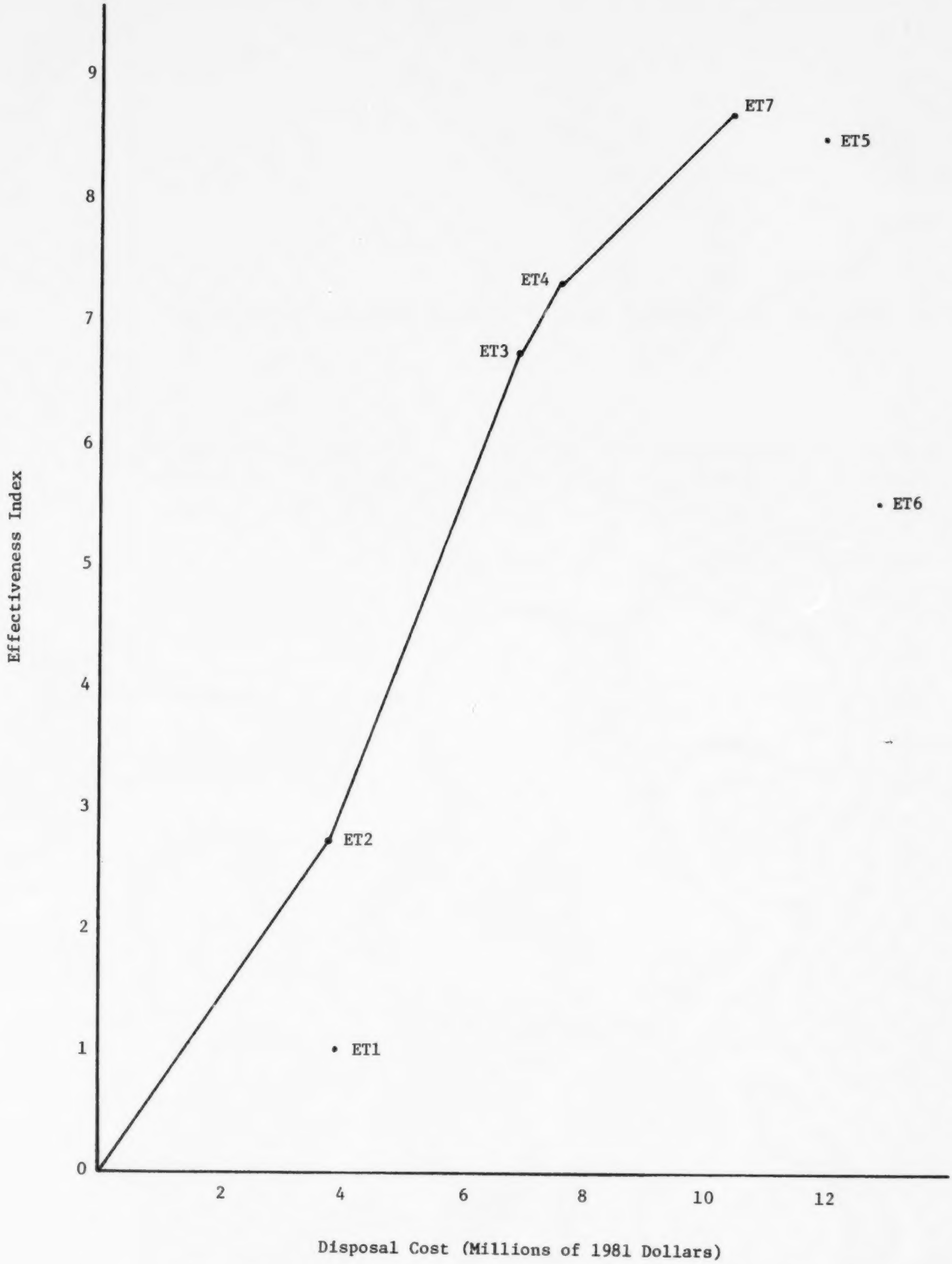

Figure 4.1. Cost-Effectiveness of Tailings Disposal Methods - Existing Tailings, 2 Million MT Pile

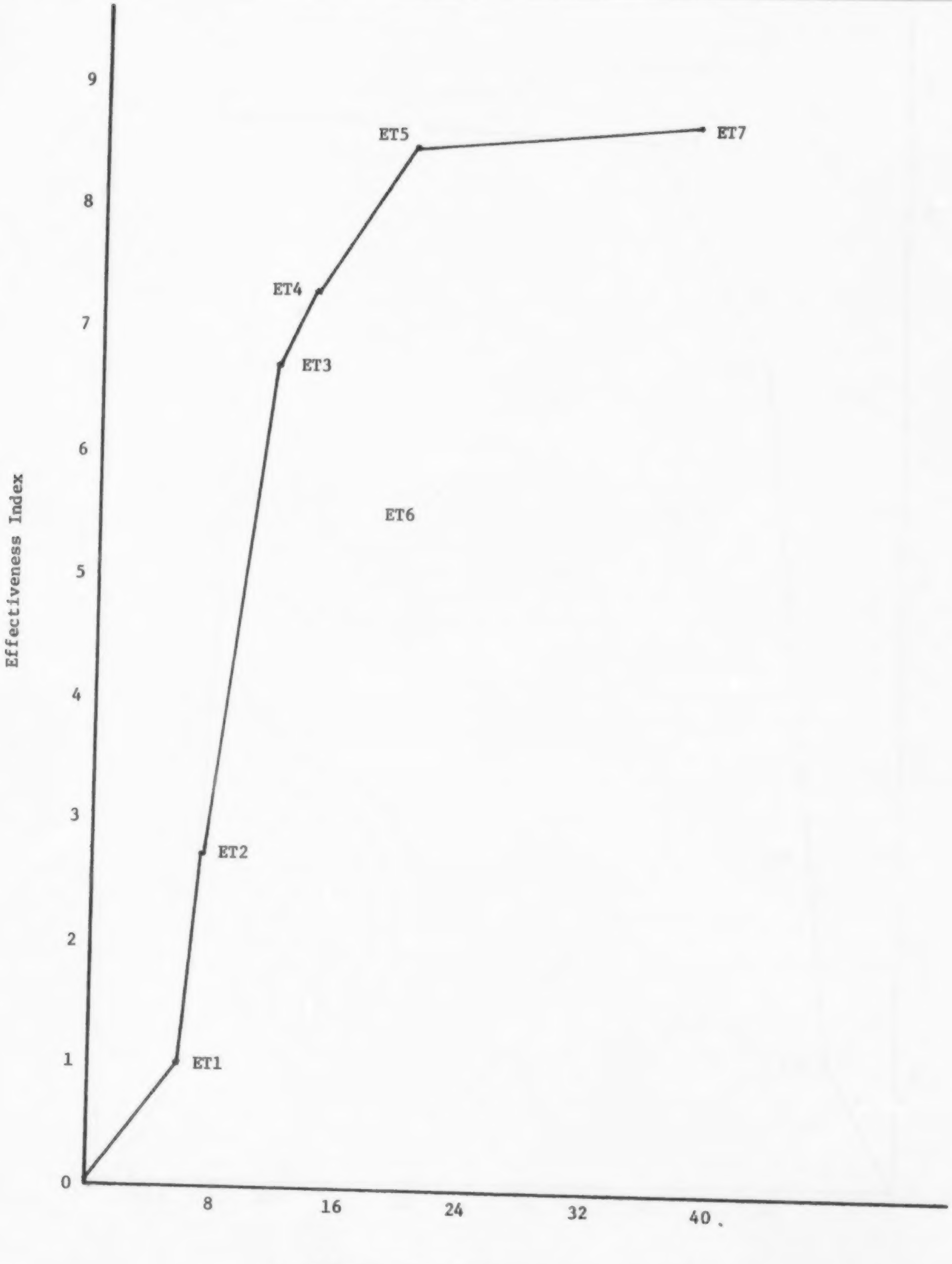

Figure 4.2. Cost-Effectiveness of Tailings Disposal Methods - Existing Tailings, 7 Million MT Pile

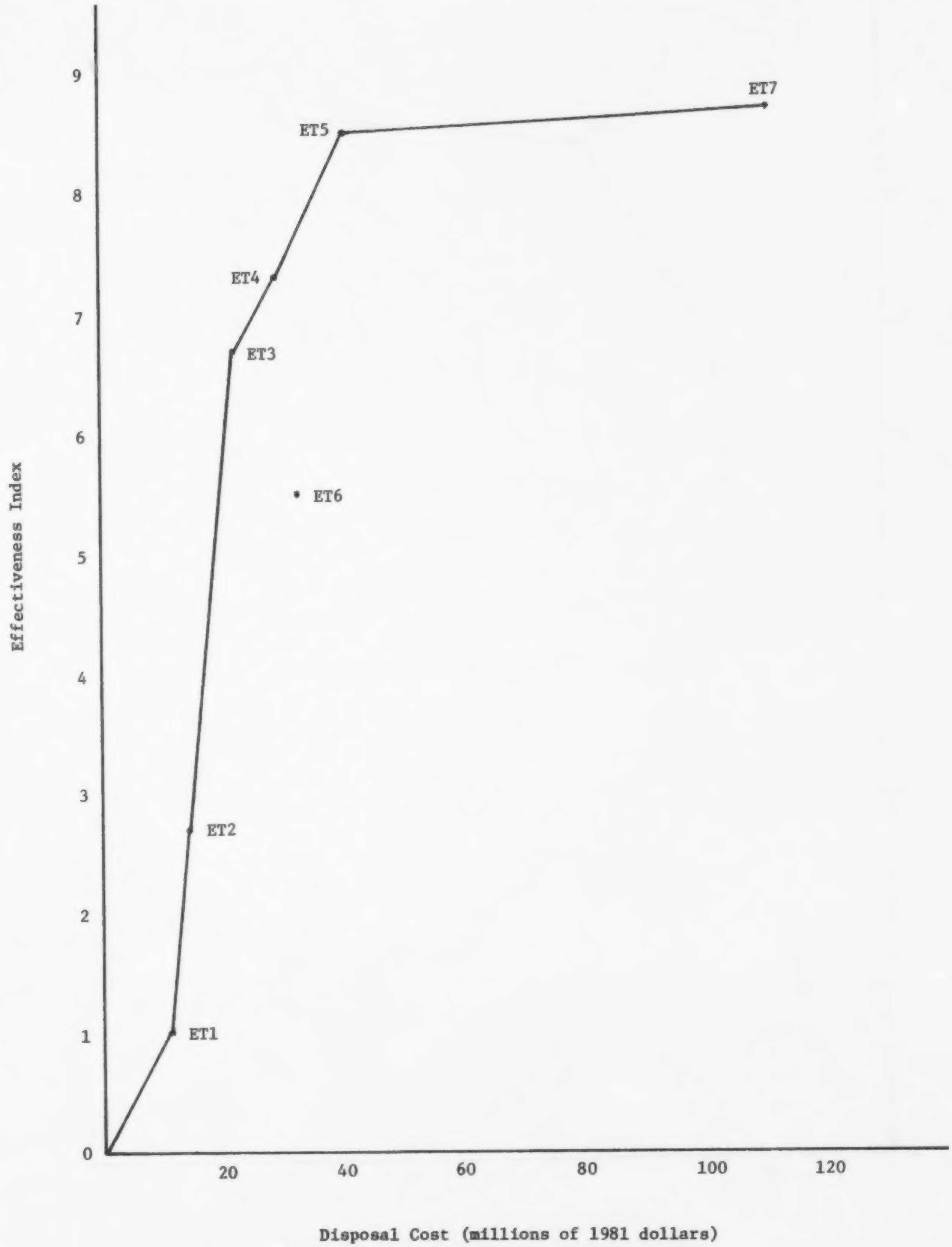

Figure 4.3. Cost-Effectiveness of Tailings Disposal Methods - Existing Tailings, 20 Million MT Pile

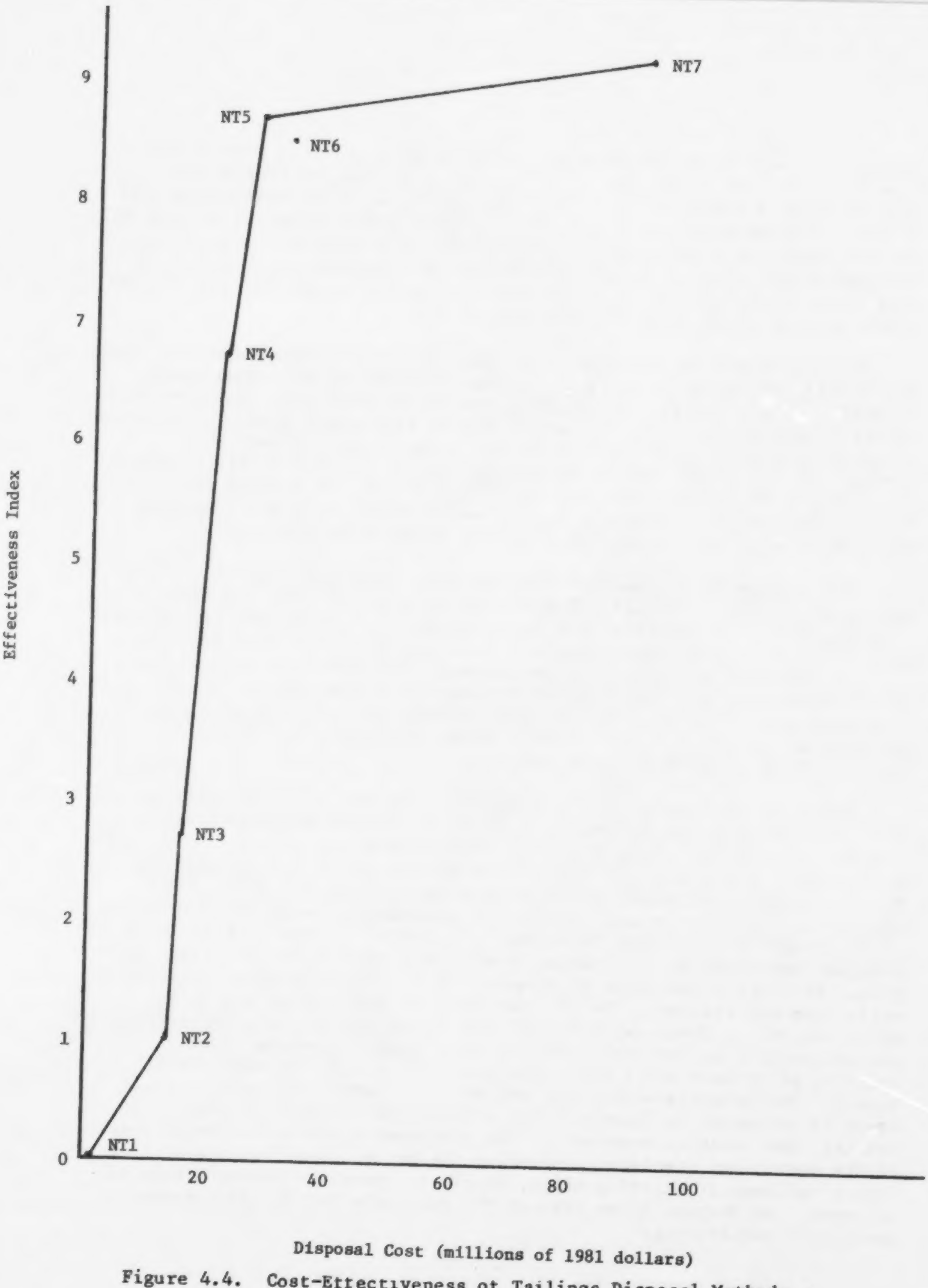

Figure 4.4. Cost-Effectiveness of Tailings Disposal Methods - New Tailings, 8.4 Million MT Pile

incremental cost increases by about a factor of 4 when one goes to ET4 from ET3. For the 20 million MT pile, the large jump in incremental cost -- about a factor of 6 -- also takes place when one goes beyond ET3 to ET4. Consequently, on a cost-effectiveness basis, disposal methods ET3 and ET4 should be considered for development of standards for existing tailings piles. Both disposal methods assume a 3-meter earth cover and rock cover on the slopes, with the only difference being that ET4 assumes a more gradual slope than ET3 (8:1 versus 5:1).

For the model new tailings pile, the incremental cost decreases from NT2 to NT3, increases by about two-thirds from NT3 to NT4, then nearly doubles from NT4 to NT5. Beyond NT5, the incremental cost increases by a factor of almost 50. Disposal method NT6 is eliminated from consideration since it is dominated by other methods. These costs indicate that controls as far as NT4 appear reasonable, while beyond NT5, it is clearly too costly. It is uncertain whether NT4 or NT5 is the optimal point. Both of these methods assume a 3-meter earth cover, with NT4 requiring above-grade disposal, while NT5 calls for below-grade disposal.

The changes in incremental cost for each model tailings pile can be seen more clearly in Figure 4.5 where the incremental cost for each disposal method is plotted. For existing tailings piles, the incremental cost decreases significantly for ET2 and stays about the same for ET3. For the 2 million ton pile, the incremental cost increases only slightly beyond ET3, while for the 7 and 20 million ton piles, the incremental cost increases significantly. For the new tailings pile, the graph shows the decrease in incremental cost to NT3, slight increases to NT4 and NT5, and the very large jump in cost for NT6.

Based on this analysis, the disposal standards for both existing and new tailings piles should require a level of control which reflects a 3-meter earth cover. This analysis, though, does not address the disposal methods that existing mills should consider for their future tailings. The regulatory requirement which determines how existing mills should dispose of their future tailings is the groundwater protection provision of the proposed operations standards. In Chapter 5, where we estimate the economic consequences of alternative disposal methods for existing and new piles, we address the issue of disposal of future tailings at existing mills from two extremes. On the one hand, we assume that all existing mills can add to their existing tailings piles indefinitely and dispose of the entire pile at one time. On the other hand, we assume that all existing mills must start new piles immediately with installation of liners. The industry-wide costs and economic impacts of each of these cases is estimated in Chapter 5 for alternative levels of control. In reality, the industry response to the groundwater protection requirement of the operations standards, regarding the implications for disposal of future tailings at existing mills, should be somewhere between these two extremes. In Chapter 6, we present the rationale for the groundwater protection requirement.

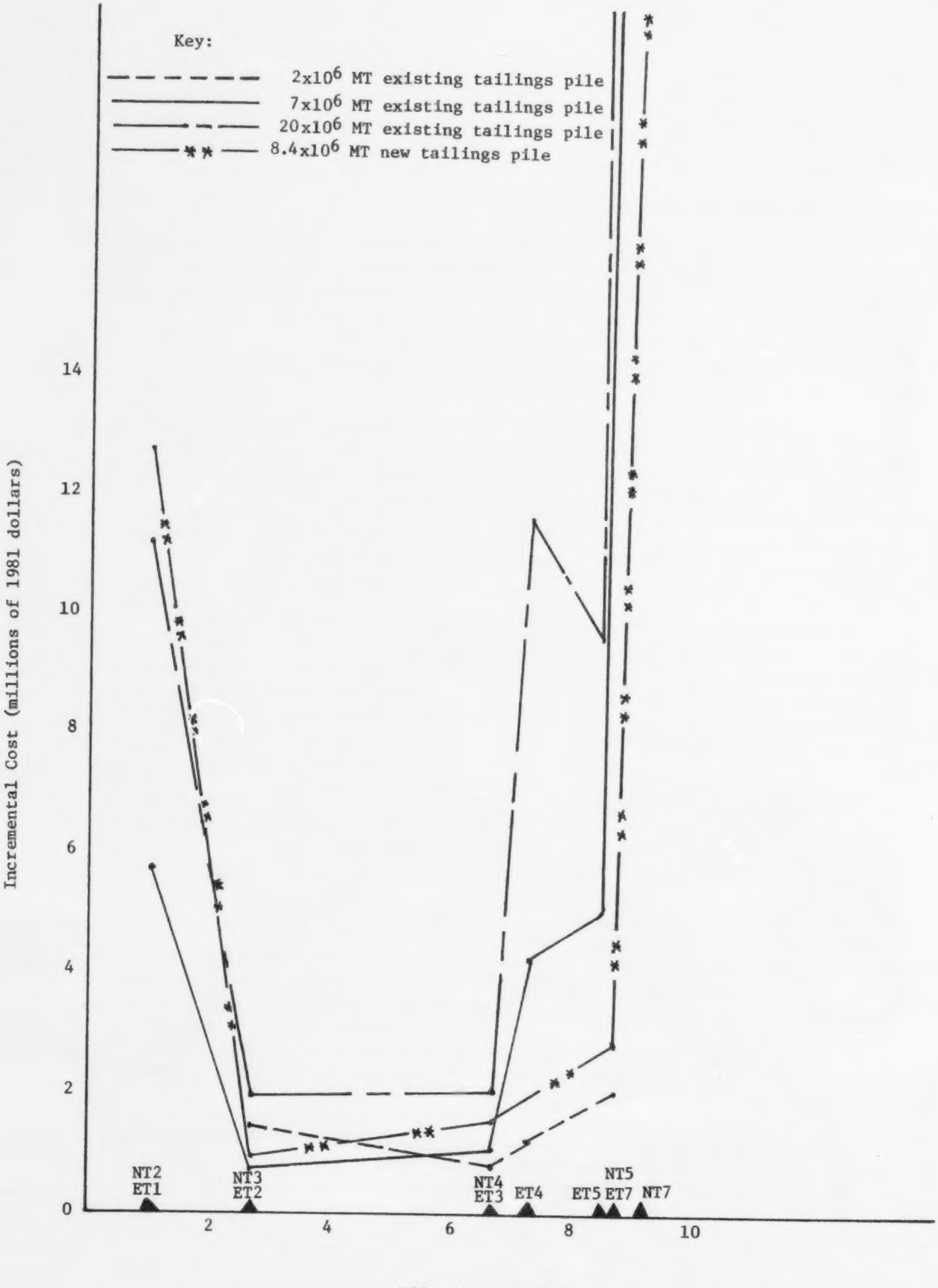

Figure 4.5. Incremental Cost of Alternative Disposal Methods

4.3.1 Sensitivity Analysis

4.3.1.1 Alternative Weighting Factors

As discussed in Section 4.2, the effectiveness index, and therefore the cost-effectiveness analysis, depends very heavily on the judgmental weighting factors for each of the classes of control. In this section, we perform a sensitivity analysis of these weighting factors. Two alternative weighting schemes were devised which represent significant diversions from the original scheme. The effectiveness index was recalculated for each of these distributions.

Table 4.8 presents the original set of weighting factors (Scheme A) and the two alternative distributions (Schemes B and C). Relative to Scheme A, Scheme B represents a substantial shift (20 percentage points) in relative importance from prevention of misuse to radon control. An additional 5 percentage points were also shifted from groundwater protection to radon control. Scheme C, on the other hand, represents a significant shift (relative to the original weighting factors) to groundwater protection (20 percentage points) from prevention of misuse.

The effectiveness index resulting from these different sets of weights is also shown in Table 4.8. These numbers indicate that the effectiveness index for the disposal methods considered in this analysis is insensitive to the selection of the weighting factors. For all the methods, except ET6, the effectiveness index either remains exactly the same for each weighting factor scheme or changes by only a few tenths of a point. The reason for this insensitivity is that the individual effectiveness ratings for each disposal method (except ET6) is about the same for each class of control. This should not be surprising since the same control technique - the earthen cover - is responsible for providing each class of control. Therefore, the relative effectiveness ratings are all based on the thickness of the cover. The index for ET6 changes by a full point when using Scheme C as compared to Scheme A. The ratings for ET6 are a 10 for surface spread, 6 for misuse, 4 for radon, and a 1 for groundwater. The rock cover placed over the entire pile for ET6 is effective in preventing surface spread and misuse, contributes little to radon control except keeps the 1-meter earth cover in place for a long time, and is counter-productive for groundwater protection since it does not allow the moisture in the tailings pile to evaporate. Consequently, a shift in the weighting factor emphasis from prevention of misuse to groundwater protection causes a noticeable change in the effectiveness index for ET6.

Since this analysis shows a lack of sensitivity, we conclude that the optimal level of control determined by the cost-effectiveness analysis is not affected by different weighting factors.

Table 4.8. Sensitivity Analysis of Weighting Factors for Effectiveness Index

Classes of Control	Alternative Weighting Factor Schemes (%)		
	A	B	C
Misuse	60	40	40
Radon	5	30	5
Surface Spread	15	15	15
Groundwater	20	15	40

Disposal Methods	Effectiveness Index		
	A	B	C
ET1	1.0	1.0	1.0
ET2	2.7	2.9	2.7
ET3	6.7	6.9	6.9
ET4	7.3	7.3	7.3
ET5	8.5	8.5	8.7
ET6	5.5	5.3	4.5
ET7	8.7	8.6	8.3
NT1	0	0	0
NT2	1.0	1.0	1.0
NT3	2.7	2.9	2.7
NT4	6.7	6.9	6.9
NT5	8.7	8.6	8.3
NT6	8.5	8.5	8.7
NT7	9.2	9.2	9.2

4.3.1.2 Alternative Time Period of Consideration

Up to this point, we have only been concerned with providing long-term protection from the hazards associated with uranium mill tailings. Long-term, in this sense, is assumed to be about 1000 years. How is this analysis affected if we alter our goal of providing long-term protection and only concern ourselves with protection for a shorter time period? This section presents the cost-effectiveness analysis of the same disposal methods but within the context of protection for a 100-year period rather than the long-term. The methodology is the same, but the effectiveness parameters have necessarily assumed different values.

In Table 4.9, we have re-assigned effectiveness ratings for each of the disposal methods to reflect each method's effectiveness in providing the four classes of control for 100 years. In comparison to the 1000-year case (Table 4.5), each disposal option has higher (or in some cases, the same) ratings which shows it is relatively more effective in providing protection for the shorter period than the longer period. The major change from the 1000-year case is in methods ET1 and NT2, which call for only one-half meter of earth cover, but provide maintenance of the tailings pile for 100 years, the entire duration of the time period now under consideration. While these disposal methods provide little long-term protection, they do provide a substantial amount of protection for 100 years. Although, by definition, the pile is maintained for 100 years, this method does not provide 100 percent protection from misuse since it does not call for continuous policing of the entire tailings pile against intrusion.

Assuming the original benefit weighting factors, we calculate the effectiveness index for each disposal method (see the last column of Table 4.9). We then perform the cost-effectiveness analysis of disposal methods. Tables 4.10 and 4.11 show the results of this analysis for the model existing and new tailings piles. For each of the model existing tailings piles, the results indicate that controls beyond the active maintenance disposal method (ET1) result in a doubling of the incremental cost in order to reach the next disposal method (ET3). Beyond ET3, the incremental cost increases by a factor of 4 (for the 7 million ton pile) or 5 (for the 2 and 20 million ton piles). This analysis shows, therefore, that if we are only concerned with providing protection for 100 years, then the standard should probably reflect active maintenance controls for existing tailings. However, the passive controls of a 3-meter earth cover (ET3) should also be considered since the incremental cost does not increase significantly. For the new tailings pile, controls beyond the active maintenance method (NT2) can be implemented with only a 50 percent increase in incremental cost. Beyond NT4, however, the incremental cost goes up by a factor of 3. Disposal with a 3-meter earth cover for new tailings piles is supported by this analysis for the 100-year protection case, the same result as in the 1000-year protection case.

Table 4.9 Effectiveness Index for Disposal Methods by Class of Control, 100-Year Protection Case

Disposal Method	Prevent Misuse	Radon Control	Prevent Spread of Tailings	Groundwater Protection	Weighted Average[a]
ET1	6	6	10	3	6.0
ET2	5	4	8	7	5.8
ET3	8	8	10	9	8.5
ET4	8	8	10	9	8.5
ET5	9	9	10	10	9.4
ET6	6	4	10	1	5.5
ET7	9	8	10	9	9.1
NT1	0	0	0	0	0
NT2	6	6	10	3	6.0
NT3	5	4	8	7	5.8
NT4	8	8	10	9	8.5
NT5	9	8	10	9	9.1
NT6	9	9	10	10	9.4
NT7	9	9	10	9	9.2

(a) The weights for this average are as follows:

I. Prevention of misuse - 60 percent
II. Radon control - 5 percent
III. Prevention of surface spread of tailings - 15 percent
IV. Groundwater protection - 20 percent

Table 4.10. Cost-Effectiveness of Disposal Methods, Existing Tailings - 100-Year Protection Case

Disposal Method	Effectiveness Index	Total Cost (10^6 1981 $)	Average Cost	Incremental Cost
2 million MT Pile				
No disposal	0	0	---	---
ET6	5.5	12.8	Eliminated	from consideration
ET2	5.8	3.8	.7	.7
ET1	6.0	3.9	.7	.5
ET3	8.5	6.9	.8	1.2
ET4	8.5	7.6	Eliminated	from consideration
ET7	9.1	10.4	1.1	5.8
ET5	9.4	11.9	1.3	5.0
7 million MT Pile				
No disposal	0	0	---	---
ET6	5.5	17.4	Eliminated	from consideration
ET2	5.8	7.0	Eliminated	from consideration
ET1	6.0	5.7	1.0	1.0
ET3	8.5	11.4	1.3	2.3
ET4	8.5	13.9	Eliminated	from consideration
ET7	9.1	38.4	Eliminated	from consideration
ET5	9.4	19.9	2.1	9.4
20 million MT Pile				
No disposal	0	0	---	---
ET6	5.5	32.5	Eliminated	from consideration
ET2	5.8	14.4	Eliminated	from consideration
ET1	6.0	11.1	1.9	1.9
ET3	8.5	22.3	2.6	4.5
ET4	8.5	29.2	Eliminated	from consideration
ET7	9.1	111.7	Eliminated	from consideration
ET5	9.4	40.6	4.3	20.3

Table 4.11. Cost-Effectiveness of Disposal Methods, New Tailings - 100-Year Protection Case

Disposal Method	Effectiveness Index	Total Cost (10^6 1981 $)	Average Cost	Incremental Cost
NT1	0	1.2	----	----
NT3	5.8	15.4	Eliminated from consideration.	
NT2	6.0	13.8	2.3	2.1
NT4	8.5	21.5	2.5	3.1
NT5	9.1	27.0	3.0	9.2
NT7	9.2	91.2	Eliminated from consideration	
NT6	9.4	31.9	3.4	16.3

REFERENCES FOR CHAPTER 4

EPA82 U.S. Environmental Protection Agency, "Regulatory Impact Analysis Guidance for Benefits," Appendix A, July 29, 1982 (unpublished draft).

NRC80 U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, September 1980.

5. Industry Cost and Economic Impact Analysis

5.1 Industry Cost Analysis

5.1.1 Overview

The purpose of this cost analysis is to estimate the industry-wide cost of mill tailings disposal for alternative combinations of disposal methods which would implicitly be required for compliance with alternative tailings disposal standards. The analysis takes into account the mix of existing tailings, future tailings generated at existing mills, and future tailings generated at new mills. Each combination of disposal methods across these three industry categories is referred to as an economic impact case.

An important limitation of this analysis involves the site-specific nature of mill tailings disposal. There are many parameters which influence the selection of a disposal method and its cost of implementation, the values of which vary from site to site. To accurately estimate the cost of compliance for each economic impact case would require an in-depth engineering study of each site. Instead, we have taken a generic approach in determining likely disposal methods and their costs. We emphasize that the costs of this analysis were developed to achieve consistency among the cases to aid in the selection of proposed standards of general application.

It is important to recognize the differences between these three industry categories. Existing tailings may require different treatments than new tailings to achieve a given level of control. In the case of new tailings (at either an existing or new mill), there is an inherent advantage to integrating tailings disposal with the waste management practices of the mill. The range of controls for existing piles are limited by the realities of the situation, where the quantity, composition, and shape of the pile must be considered in developing remedial action programs. For disposal of future tailings, new mills have an advantage over existing mills since tailings management can be factored into the decision on locating the mill. There are also important differences in the financial considerations faced by existing mills and new mills. Mills with existing tailings have the burden of financing the disposal of existing tailings in addition to financing the disposal of future tailings. Also, existing mills generally have fewer remaining years of plant life over which to finance tailings disposal than new mills. The additional burden of existing tailings disposal cost and the relatively less remaining plant lifetime may result in existing mills experiencing greater economic handicaps than new mills.

5.1.1.1 Formulation of Economic Impact Cases

We developed 22 economic impact cases for the industry cost analysis. These cases are defined in Table 5.1. We recognize that many other combinations are possible, but we feel that the 22 cases designated

Table 5.1. Tailings Disposal Methods,
By Economic Impact Case and Industry Category

Economic Impact Case	Existing Mills/ Existing Tails	Existing Mills/ Future Tails	New Mills
A	--	--	NT1
B_1	--	--	NT3
B_2	--	--	NT5
B_3	--	--	NT7
C	ET1	ET1	NT2
D	ET1	ET1	NT5
E	ET2	ET2	NT3
F	ET2	ET2	NT4
G	ET6	ET6	NT5
H_1	ET3	ET3	NT4
H_2	ET3	ET3	NT5
H_3	ET4	ET4	NT5
H_4	ET5	ET5	NT6
I	--	NT5	NT5
J	ET1	NT5	NT5
K	ET2	NT4	NT4
L	ET6	NT5	NT5
M_1	ET3	NT4	NT4
M_2	ET3	NT5	NT5
M_3	ET4	NT5	NT5
M_4	ET5	NT6	NT6
N	ET7	NT5	NT5

for study are viable from a regulatory perspective, provide sufficient degrees of variation, and keep the scope of the analysis manageable in terms of the number of cases to be considered.

The 22 impact cases fall into two general groups according to the treatment of future tailings at existing mills. In one set of cases (A through H), this industry category is treated exactly like the existing tailings category and, thus, the same disposal methods are assumed for each. In the other set of cases (I through N), future tailings at existing mills are treated the same as future tailings at new mills. Consequently, for these cases we assume that existing mills will separate their future tailings from the tailings which already exist and start new piles. In the first set of cases, this separation of tailings at existing mills is not required. In most instances, the controls for future tailings at new mills are more severe than those for existing tailings piles since we recognize the economic and engineering implications of making extensive remedial actions to the existing piles.

The cost for a protective liner is included in the disposal cost estimates for new mills for every impact case (except Case A) even though the liner requirement is not due to the proposed disposal standards, as explained in Chapter 1. We included the liner cost in this analysis in order to estimate the complete economic impact related to mill tailings disposal, regardless of which regulatory provision is responsible for its use.

The following paragraphs present a brief description of each impact case.

Case A is the no control case for each industry category. Existing tailings are assumed to remain unaltered, while future tailings at both existing and new mills are assumed to be treated in the same way that existing tailings have been treated in the past. Under this option, there are no disposal costs for existing tailings and future tailings at existing mills. For future tailings at new mills, the cost of preparation of the initial tailings basin is included in the cost of disposal.

Case B calls for no control for both existing tailings and future tailings at existing mills, but does require disposal of future tailings at new mills. At new mills, three degrees of control are considered: disposal above-grade with a 1-meter earth cover; below-grade disposal with 3 meters of earth cover; and solidification of the tailings in cement.

Case C provides no long-term controls but does require a .5-meter earth cover and active maintenance of these tailings piles for 100 years for each industry category.

Case D is the same as Case C for existing tailings and future tailings at existing mills. Below-grade disposal with a 3-meter earth cover is assumed for new mills.

Case E assumes a 1-meter earth cover with rocks on the slopes for each industry category.

Case F is the same as Case E for existing tailings and future tailings at existing mills. Above-grade disposal with a 3-meter earth cover is assumed for new mills.

Case G calls for a 1-meter earth cover, plus rock cover over the entire tailings pile for existing tailings and future tailings at existing mills. Below-grade disposal with a 3-meter earth cover is assumed for new mills.

Case H includes four different combinations of 3- and 5-meter earth covers for each of the tailings categories. Variations in slope and above-grade versus below-grade disposal are considered.

Case I calls for no control of existing tailings, but assumes below-grade disposal with a 3-meter earth cover for future tailings at both existing and new mills.

Case J is the same as Option I except that it requires a 0.5-meter earth cover plus active maintenance for 100 years for existing tailings.

Case K assumes a 1-meter earth cover plus rock cover on the slopes at existing tailings piles while it requires 3 meters of earth with rock cover on the slopes for future tailings at both existing and new mills.

Case L assumes a 1-meter earth cover plus rock cover over the entire tailings pile for existing tailings, and below-grade disposal with a 3-meter earth cover for future tailings at both existing and new mills.

Case M is the same as Case H in that it considers four different combinations of 3- and 5-meter earth covers for the different tailings categories. However, new tailings disposal methods are assumed for future tailings at existing mills rather than existing tailings disposal methods.

Case N assumes that all tailings are placed below-grade with a 3-meter earth cover. This requires the moving of all existing tailings piles plus the placement of a liner at the new sites.

With this analytical framework, we can estimate the incremental impact of requiring different levels of control on the different industry categories.

5.1.1.2 Estimation Methodology

Three types of model entities were used in this analysis. Model existing tailings piles and a model new tailings pile (described in Chapter 4) were developed to estimate the costs of alternative disposal methods. Model uranium mills were developed to analyze the affordability of the tailings disposal costs by the mills. Section 5.1.2.2 presents a summary description of the model mills while an in-depth discussion is found in Appendix A.

For existing tailings, the cost for each disposal method was estimated for three models of existing tailings piles. The estimated cost of disposal for the model existing piles is assumed to apply to each of the piles in that size group. The summation of these costs yields the total cost for disposal of the existing tailings inventory. In light of the aforementioned caveat, we realize that this cost estimation may be inappropriate for representing the disposal cost of a given pile. However, for representing the average cost for a group of similiarly-sized piles, we feel that this methodology is justified in that some sites will undoubtedly cost more while others cost less.

To estimate the cost of disposal for future tailings, we assume that mill operators will set aside funds each year to cover the cost of disposal for the tailings generated in that year. The industry-wide annual cost of disposal is determined by applying an appropriate unit cost of disposal ($/MT of tailings) to the units (MT) of tailings generated in that year. Therefore, the cost of disposal for future tailings is assumed to occur at the time the funds are collected and not at the time the disposal activities take place.

We assumed that the industry demand forecast is unaffected by the EPA standards. Therefore, this industry forecast is the same for all economic impact cases. However, we have further assumed that the standards may have an impact on the relative shares of future industry production supplied by existing and new mills. The projection of annual mill tailings generation, segmented by existing and new mills, is a function of the amount of existing capacity projected to operate in the future. To determine projected capacity of existing mills, we have performed a plant closure analysis for each impact case. This analysis investigates the relationship between the disposal cost for mill tailings and the mill operator's decision on whether they can profitably continue production. Since each impact case results in different disposal cost estimates, the plant closure analysis was performed for each case. The analysis was conducted for several model mills and provided an estimate of the existing industry capacity that can be expected to remain in operation. Appendix A presents an in-depth description of the plant closure analysis.

After the estimates of industry capacity are derived, projections of industry production at existing mills can then be made. Production at new mills is assumed to equal the remaining portion of the aggregate industry demand forecast not produced at existing mills after consideration of changes in inventories, retired industry capacity, plant utilization rates, and plant closings due to tailings disposal costs. Appendix B presents the annual projections of industry production for each impact case, segmented by existing and new mills.

For future tailings at new mills, the unit cost of disposal ($/MT of tailings) from the model pile cost analysis is applied to the annual projections of industry production at new mills to derive the annual industry cost of disposal.

The unit cost of disposal of future tailings at existing mills is derived from both the cost estimations for the three model existing piles and the model new pile, depending on the individual impact case. If the case allows existing mills to add future tailings to their existing piles (Cases C through H), then the unit cost of disposal for the future tailings is assumed to equal the incremental unit cost of disposal estimated from the costs of the three model existing piles. If the case requires existing mills to start new piles for future tailings (Cases I through N), then the unit cost of disposal for existing mills, future tailings, assumed the same value as that derived for the model new pile.

Once the projections of industry production and the estimations of unit costs by category have been made, then the calculation of the aggregate cost of compliance to the uranium milling industry can be performed. As stated earlier, applying the unit cost of disposal to the quantity of tailings generated each year provides an estimate of the annual cost of disposal for future tailings, derived separately for existing mills and new mills. Since the existing tailings inventory has been estimated as of the end of 1979, future tailings are defined as the tailings generated from 1980 through the year 2000.

For existing tailings, we assumed that the entire industry disposal cost will be incurred over the five-year period, 1980 through 1984. We allocated the total cost in equal amounts to each of the five years. This does not mean that disposal activities will necessarily take place during this time frame, but rather that this is the time over which we assumed the money to pay for the disposal will be raised.

These calculations result in the development of three categories of yearly flows of disposal costs from 1980 to 2000: existing mill tailings, future tailings generated at existing mills, and future tailings generated at new mills. The yearly flows of industry costs are presented for each impact case in Appendix C. A present worth analysis of the costs was also performed for each case. The present worth estimates were calculated for three alternative discount rates and two industry demand scenarios. The three discount rates are 10, 5, and 0 percent. The two industry demand scenarios are a baseline projection, based on a DOE mid-range reactor forecast, and a low-growth industry projection representative of either a significant reduction in reactor capacity or an increased reliance on U_3O_8 imports.

5.1.2 Cost Estimation

Following the procedure explained above, we have estimated the industry-wide cost of each impact case for each industry category. The sum of the costs for the three industry categories represents the total cost for the case. The total cost is expressed in several ways according to different scenarios for the discount rate and forecasts of milling industry demand.

5.1.2.1 Existing Tailings

Table 5.2 presents the total disposal cost for the 23 existing tailings piles. These costs were derived by multiplying the appropriate model pile cost (from Chapter 4) by the number of piles in that model-size category. As the table indicates, there are no costs for Cases A, B, and I since these cases call for no controls for existing tailings. As stated above, we assume that the costs are to be funded in five equal increments over the period 1980 to 1984.

5.1.2.2 Future Tailings

For future tailings at both existing and new mills, the annual industry disposal cost was derived by multiplying the appropriate unit cost of disposal by the industry production projected for each year. Table 5.3 presents for each impact case the industry unit cost of disposal for existing and new mills. These costs are expressed on the basis of dollars per metric ton of U_3O_8 (converted from unit costs on a tailings basis) and are applied to the industry U_3O_8 production estimates presented in Appendix B.

For Cases C through H, the existing mill costs are the simple average of the two incremental unit cost estimates for the three model existing tailings piles. The first incremental unit cost is estimated by dividing the difference in total cost for the 2 and 7 million MT piles by the tonnage difference. Similarly, the second incremental unit cost is estimated by dividing the difference in total cost for the 7 and 20 million MT piles by the tonnage difference. These calculations were made for each disposal method. The incremental cost per ton of tailings is about the same for both the 2 to 7 million ton comparison and the 7 to 20 million ton comparison. Therefore, the average of the two incremental unit costs was used to represent the industry unit cost.

This incremental unit cost may overstate the actual cost of disposing of future tailings at some existing mills where substantial tailings impoundment capacity exists. The incremental unit cost calculation estimates the difference in the cost of covering piles having not only different quantities of tailings, but also significantly different surface areas. The surface area of the pile is a key determinant of the tailings disposal cost. Mills with plenty of tailings capacity remaining in their existing impoundment configuration can add to their piles without changing the height of their tailings impoundment and, therefore, the amount of surface area required for placement of the earthen cover. In these cases, the incremental unit cost may overstate the unit cost of disposing of future tailings. In cases where the existing tailings impoundment must be expanded, the incremental unit cost appears to be a reasonable approximation. Without doing a site-by-site investigation of tailings capacity at existing mills and without being able to project at which existing mills future production will take place, and how much, we cannot determine to what extent our estimates may be overstated.

Table 5.2 Total Disposal Cost for Existing Tailings (23 Piles), By Economic Impact Case (Millions of 1981 Dollars)

Economic Impact Case	Pile Size: (10^6 MT)	2	7	20	Total Cost
	# of Piles:	10	10	3	
A		-	-	-	-
B_1		-	-	-	-
B_2		-	-	-	-
B_3		-	-	-	-
C		39	57	33	129
D		39	57	33	129
E		38	70	43	151
F		38	70	43	151
G		128	174	98	400
H_1		69	114	67	250
H_2		69	114	67	250
H_3		76	139	88	303
H_4		119	199	122	440
I		-	-	-	-
J		39	57	33	129
K		38	70	43	151
L		128	174	98	400
M_1		69	114	67	250
M_2		69	114	67	250
M_3		76	139	88	303
M_4		119	199	122	440
N		124	437	382	943

Table 5.3. Industry Unit Costs for Disposal of Future Tailings (1981 dollars)

Economic Impact Case	Existing Mills		New Mills	
	($/MT Tailings)	($/MT U_3O_8)	($/MT Tailings)	($/MT U_3O_8)
A	--	--	0.14	151
B_1	--	--	3.26	3505
B_2	--	--	4.27	4590
B_3	--	--	10.85	11664
C	0.39	419	3.07	3300
D	0.39	419	4.27	4590
E	0.60	645	3.26	3505
F	0.60	645	3.99	4289
G	1.04	1118	4.27	4590
H_1	0.87	935	3.99	4289
H_2	0.87	935	4.27	4590
H_3	1.22	1312	4.27	4590
H_4	1.60	1720	5.23	5622
I	4.27	4590	4.27	4590
J	4.27	4590	4.27	4590
K	3.99	4289	3.99	4289
L	4.27	4590	4.27	4590
M_1	3.99	4289	3.99	4289
M_2	4.27	4590	4.27	4590
M_3	4.27	4590	4.27	4590
M_4	5.23	5622	5.23	5622
N	4.27	4590	4.27	4590

For Cases I through N, the industry unit cost for existing mills is the same as the industry unit cost for new mills since these cases assume that future tailings at existing mills will be disposed in the same manner as future tailings at new mills. The industry unit cost for new mills in Table 5.3 is the appropriate unit cost for the model new pile (from Chapter 4). The average unit cost for the model new pile may understate the actual disposal cost for future tailings for those mills whose future generation is less than that assumed for the model new pile (8.4 million MT). The understatement of cost will occur if the economy of scale relationship that we observe for the existing tailings piles is applicable to new piles. Since we have assumed one model new pile size, we have only one data point and, therefore, cannot accurately test for scale economies. Nevertheless, for representing an industry average unit disposal cost, the model new pile cost appears reasonable since some mills will generate more than 8.4 million MT of tailings and, therefore, partially offset the diseconomy of scale from the mills with limited future production.

Mill Closure Analysis

As stated earlier, we assume that the forecast of industry demand for U_3O_8 is the same for each case; in other words, total demand is unaffected by the EPA standard. However, industry production at existing mills versus new mills may differ by impact case according to the results of the plant closure analysis. The plant closure analysis is based on the use of a discounted cash flow (DCF) technique which indicates whether or not a project is justified on economic grounds. The DCF analysis compares, on a model mill basis, the discounted cost of disposal for each case to the discounted cash flow over the life of the project. The cash flow (pre-tax) for this analysis is defined to be 20 percent of revenues (15 percent operating profit plus 5 percent depreciation and depletion). We also assume that the entire cost of disposal for both existing and future tailings is absorbed by the mill with no price pass-through. Considering the disposal costs for both existing and future tailings may overstate the financial impact if one assumes that the mills have already assumed the liability for the disposal of existing tailings. For conservatism, we did not make this assumption. If the discounted cash flow is greater than the discounted cost of disposal, then we conclude that the model mill will continue operation. If the reverse is true, then the mill closes. By assuming a fixed industry demand, the gap created by any mill closures must be filled by either increased capacity utilization rates for mills which continue to operate, reduced inventories, or additional new mill capacity. Consequently, the occurence of mill closures due to tailings disposal costs will result in varying projections of existing and new mill production for each case. The effects of varying the cash flow and cost absorption assumptions on the plant closure analysis are discussed in the sensitivity analysis section of Appendix A.

For the plant closure analysis, model mills are distinguished by three parameters: capacity of the mill, remaining operating life of the mill, and the size of existing tailings pile. Three mill capacities (900, 1800, and 2700 MT per day), three operating lives (5, 10 and 15 years), and three sizes of existing piles (2, 7, and 20 million MT) are assumed. These assumptions result in 27 (3x3x3) possible model mills for the analysis. After examining the characteristics of the licensed uranium mills, we have placed each of them in one of 15 model mill categories. A separate analysis was performed for each of the 15 model mills and for each impact case. Table 5.4 summarizes the results of the plant closure analysis for the baseline and low-growth industry demand scenarios. Appendix A presents a detailed description of the methodology and results of the analysis.

Projections of Industry Production and Disposal Costs

Two projections of industry demand for conventionally-milled U_3O_8 were considered in this study. A baseline projection was derived which corresponds to a mid-range forecast of U.S. installed reactor capacity. An alternative projection - the low growth industry demand scenario - was derived to represent a severe reduction in the growth of the conventional U.S. uranium milling industry. Although a very low forecast of installed reactor capacity was used to derive this demand for U_3O_8, this projection can be used to also represent the case of a strong reliance on imported U_3O_8. These projections, made on an annual basis from 1980 through 2000, are shown in Table 5.5, accompanied by their respective uranium price projections.

Based on the projection of industry demand, the existing U_3O_8 inventory and the existing uranium mill capacity, we have estimated, year-by-year, the industry production necessary to meet the demand for domestically produced uranium. The methodology, which is explained in depth in Appendix B, considers the following: new capacity which would come on line in the absence of regulatory controls (Case A), the obsolescence of existing capacity (permanently retired due to economic reasons), the industry's annual average capacity utilization rate, and premature mill closings (temporary reductions in capacity needed to work off the abnormally high level of inventories, as discussed in Chapter 2). Based on the new and existing mill capacities and the industry average capacity utilization rate, annual industry production is calculated for both new and existing mills. Upon considering the mill closures (Table 5.4) due to the disposal costs for each case, additional premature closures may result which, in turn, forces changes in the inventory level, capacity utilization rate, and addition of new mill capacity, in order to meet the industry demand. Separate tables for each impact case (or group of cases resulting in the same number of mill closures) showing the yearly changes to each of these parameters are also presented in Appendix B.

Table 5.4. Summary of Mill Closure Analysis, Baseline and Low Growth Industry Demand Scenarios(a)

Economic Impact Case	Model Mill Closures	Equivalent Number of Small Mills(b)
A, B, C, D, E, F, H_1, H_2, I, J and K	No Closures	0
H_3, M_1, M_2, and M_3	1 small	1
G	2 small	2
H_4	1 small, 1 large	4
L and M_4	2 small, 1 large	5
N	5 small, 1 medium 3 large	16

(a)Based on assumptions of 100 percent cost absorption and 20 percent cash flow margin.

(b)Based on mill capacity,
1 medium mill = 2 small mills
1 large mill = 3 small mills

Table 5.5. Projection of Industry Demand and Price of U_3O_8, 1980-2000

	Baseline Industry Demand(a)		Low Growth Industry Demand(b)	
Year	10^3 MT U_3O_8	Price (1981 $ per pound of U_3O_8)	10^3 MT U_3O_8	Price (1981 $ per pound of U_3O_8)
1980	12.5	29.3	12.5	29.3
1981	13.6	30.7	13.6	30.7
1982	14.9	32.1	14.9	32.1
1983	15.3	33.5	15.2	33.5
1984	16.0	34.8	15.8	34.8
1985	16.6	36.2	16.3	36.2
1986	17.3	37.6	16.8	37.6
1987	18.0	39.0	17.1	39.0
1988	17.9	40.3	16.7	39.2
1989	17.9	41.7	16.4	39.3
1990	18.2	43.1	16.3	39.5
1991	18.7	44.5	16.5	39.6
1992	19.2	45.9	16.6	39.8
1993	20.3	47.2	16.7	39.5
1994	21.4	48.6	16.8	39.3
1995	22.5	50.0	16.9	39.1
1996	23.5	51.4	16.8	38.8
1997	24.6	52.7	16.9	38.5
1998	25.8	54.1	16.1	36.9
1999	27.0	55.5	15.4	35.4
2000	28.4	56.9	14.8	34.0

(a) Based on the following forecast of installed reactor capacity (GWe): 1985 = 96; 1990 = 128; 1995 = 145; and 2000 = 175.

(b) Based on the following forecast of installed reactor capacity (GWe) 1985 = 96; 1990 = 122; 1995 = 125; and 2000 = 120

By applying the industry unit disposal costs (Table 5.3) to the estimates of production at new and existing mills (Appendix B tables) we derive the annual disposal cost for future tailings at new and existing mills. Appendix C presents the yearly flows of these disposal costs, along with the existing tailings disposal costs, for each impact case. A separate set of cost tables are presented for each of the industry demand scenarios. The cumulative costs for each economic impact case, segmented by industry category, are presented in Tables 5.6 and 5.7 for both demand scenarios.

5.1.2.3 Present Worth Analysis

Once the yearly flows of costs have been derived, we can then perform a present worth cost analysis of the economic impact cases. For each industry demand scenario, the present worth cost for each case has been calculated for three different discount rates (0, 5, and 10 percent). The results of the present worth analysis are shown in Table 5.8. For comparison purposes the ordinal rankings of each case are presented in Table 5.9.

Table 5.9 shows the sensitivity of varying the discount rate. Several changes in the relative ranking of the cases occur, but only one case appears to be significantly affected by varying the discount rate. For the baseline industry demand scenario, Case B_3 is ranked the ninth most expensive using a 10 percent rate, third most expensive with a 5 percent rate, while on an undiscounted basis this case is the most costly. For the low-growth industry demand scenario, Case B_3 is ranked thirteenth for a 10 percent rate, tenth for a 5 percent rate, and third for a zero rate. A closer look at this case explains this variability. Case B_3 is extremely costly for future tailings at new mills but calls for no controls at existing mills for either existing or future tailings. Therefore, the very high unit disposal costs are applied to new mill production which grows rapidly throughout the 21-year projection period. Discounting has a very large impact for this case since the years where its greatest costs are incurred are given the least weight.

5.2 Economic Impact Analysis

5.2.1 Introduction

The purpose of this section is to present an analysis of the economic impacts associated with the costs of the various cases. The intent is to present the methodology for estimating the impacts and the range of results for all cases. In Chapter 6, we summarize the economic impacts associated with the proposed standards. For discussion purposes, the economic impacts are presented at three separate levels: the uranium industry level, the regional level, and the macroeconomic level. Although the three levels are presented separately, they are closely interrelated.

Table 5.6. Cumulative Industry Disposal Costs, 1980-2000 - Baseline Industry Demand Scenario (millions of 1981 dollars, undiscounted)

Economic Impact Case	Existing Tailings	Future Tailings, Existing Mills	Future Tailings, New Mills	Total Cost
A	0	0	42	42
B_1	0	0	952	952
B_2	0	0	1244	1244
B_3	0	0	3170	3170
C	129	59	897	1085
D	129	59	1244	1433
E	151	93	952	1196
F	151	93	1164	1408
G	400	159	1244	1803
H_1	250	133	1164	1547
H_2	250	133	1244	1627
H_3	303	186	1244	1733
H_4	440	244	1526	2210
I	0	652	1244	1896
J	129	652	1244	2026
K	151	610	1164	1926
L	400	636	1242	2277
M_1	250	610	1164	2024
M_2	250	652	1244	2146
M_3	303	652	1244	2199
M_4	440	780	1523	2742
N	943	476	1373	2792

Table 5.7. Cumulative Industry Disposal Costs, 1980-2000 - Low Growth Industry Demand Scenario (millions of 1981 dollars, undiscounted)

Economic Impact Case	Existing Tailings	Future Tailings, Existing Mills	Future Tailings, New Mills	Total Cost
A	0	0	25	25
B_1	0	0	610	610
B_2	0	0	757	757
B_3	0	0	1929	1929
C	129	63	546	738
D	129	63	757	950
E	151	98	580	829
F	151	98	709	958
G	400	169	757	1326
H_1	250	141	709	1100
H_2	250	141	757	1149
H_3	303	198	757	1258
H_4	440	259	978	1676
I	0	694	757	1451
J	129	694	757	1580
K	151	649	709	1509
L	400	674	781	1855
M_1	250	649	709	1607
M_2	250	694	757	1701
M_3	303	694	757	1753
M_4	440	826	958	2224
N	943	505	881	2329

Table 5.8. Present Worth Cost[a] of Economic Impact Cases
(millions of 1981 dollars)

Economic Impact Case	Baseline Demand			Low Growth Demand		
	Discount Rate: 10%	5%	0%	Discount Rate: 10%	5%	0%
A	10	19	42	6	12	25
B_1	219	441	952	149	291	610
B_2	286	576	1244	187	364	757
B_3	728	1467	3170	477	927	1929
C	337	570	1085	267	419	738
D	417	731	1433	319	520	950
E	384	639	1196	310	479	829
F	433	737	1408	342	541	958
G	676	1037	1803	580	829	1326
H_1	530	851	1547	440	657	1100
H_2	549	888	1627	452	680	1149
H_3	618	973	1733	522	766	1258
H_4	818	1264	2210	709	1030	1676
I	644	1047	1896	555	853	1451
J	742	1159	2026	653	965	1581
K	718	1111	1926	634	929	1509
L	940	1382	2277	855	1198	1855
M_1	793	1196	2024	708	1015	1607
M_2	834	1263	2146	744	1070	1701
M_3	874	1309	2199	784	1115	1753
M_4	1115	1651	2742	1010	1425	2224
N	1333	1828	2792	1231	1619	2329

(a)Discounted to the beginning of 1980.

Table 5.9. Ordinal Ranking of Present Worth Cost of Economic Impact Cases (#1 is the most expensive)

Economic Impact Case	Baseline Demand			Low Growth Demand		
	Discount Rate:			Discount Rate:		
	10%	5%	0%	10%	5%	0%
A	22	22	22	22	22	22
B_1	21	21	21	21	21	21
B_2	20	19	18	20	20	19
B_3	9	3	1	13	10	3
C	19	20	20	19	19	20
D	17	17	16	17	17	17
E	18	18	19	18	18	18
F	16	16	17	16	16	16
G	11	12	12	10	12	12
H_1	15	15	15	15	15	15
H_2	14	14	14	14	14	14
H_3	13	13	13	12	13	13
H_4	6	6	5	6	6	8
I	12	11	11	11	11	11
J	8	9	8	8	8	9
K	10	10	10	9	9	10
L	3	4	4	3	3	4
M_1	7	8	9	7	7	5
M_2	5	7	7	5	5	7
M_3	4	5	6	4	4	6
M_4	2	2	3	2	2	2
N	1	1	2	1	1	1

There is a significant amount of uncertainty in predicting the future course of the uranium industry. The initial source of the uncertainty is the schedule of installed reactor capacity from which the demand for uranium can be derived. The conditions surrounding this uncertain forecast were discussed in Chapter 2. We have attempted to circumvent this problem in our analysis by using two alternative demand projections which are far enough apart so that the estimated impacts for each case will provide a broad, yet realistic, range, inside which we feel the actual impacts will result.

Given each uranium demand scenario, it is highly uncertain how this demand will be met. Due to lower cost foreign uranium deposits and public utility commission objectives on the one hand, and potential import restrictions and utilities' "Buy American" policies on the other hand, we cannot accurately determine how much of this demand will be provided by foreign sources versus domestic sources (see Chapter 2). Regarding domestic production, we do not know for certain how long existing mills will continue to remain in operation. Mills have closed for a variety of reasons, including exhaustion of economically-produced ore deposits, financial problems, and a pessimistic long-run outlook on the uranium industry by the parent corporation compared to other business ventures. If we had information on each mill's existing contracts, we might be in a better position to estimate their remaining lifetimes. However, even this information would not be conclusive since some mills with long-term contracts have still shut down and are honoring their contracts by making purchases on the spot market from buyers with excess supply. These uncertainties also prevent us from making an accurate projection of uranium prices.

Based on the information that we had on the uranium industry, we developed two projections of the industry corresponding to the two demand scenarios which takes into account the working down of existing excess inventories, retirements of capacity due to exhaustion of ore deposits, additions of new capacity, variable capacity utilization rates, and premature closings due to market conditions. Industry average uranium prices were also projected. These projections of uranium industry activity are necessary so that we can measure the economic impacts of the standards. The impacts estimated in this chapter are intended to show the incremental effects of tailings disposal and are not intended to be a prediction on what we think the future of the industry will be like. Based on all these uncertainties, we do not feel that accurate predictions of the uranium industry can be made.

5.2.2 Uranium Industry Impacts

5.2.2.1 Production Cost Increases and Potential Price Effects

One method of estimating the economic impact at the uranium industry level is to examine the percentage increase in production cost represented by the additional costs of tailings disposal. This cost increase would vary by individual mill since the production capacity, remaining lifetime, and size of existing tailings pile each affect the amount of the disposal cost. On a relative basis, the larger cost increases would result in those cases represented by small capacity, few years of remaining lifetime, and large quantities of existing tailings. Table 5.10 shows the range in percentage production cost increases across the model mills for each impact case, assuming a base production cost of $30 per pound of U_3O_8. Cost increases for the least impacted model existing mill vary across impact cases from 1.2 to 10.3 percent. The cost increase for the most impacted existing mill varies from 7.1 to 67.6 percent. Alternatively, the estimates of cost increases were arranged to show the range across all cases for each model existing mill, as presented in Table 5.11. The percentage cost increase is estimated to range from 2.2 percent to 67.6 percent for a small model mill. For a medium-sized model mill, the percentage cost increase ranges from 1.4 percent to 20.7 percent. For a large model mill, the percentage cost increase ranges from 1.2 percent to 65.8 percent. For a model new mill, the percentage cost increase ranges from 0.2 percent to 18.1 percent. Appendix A (Tables A-9, A-10, A-11c, and A-12) shows the complete results for all model mills.

For some cases and model mills, the production cost increases are quite large. In light of the depressed condition of the uranium industry and the threat from foreign competition, it is highly unlikely that all of the costs of tailings disposal can be passed on to customers. However, it is possible that part of the control costs could be passed-through in the form of higher prices since: (1) all of the existing mills and new mills are subject to control costs (although control costs may vary across the industry, the industry as a whole should pass-through at least a part of the control costs), (2) as discussed in Chapter 2, the demand for uranium is inelastic with respect to price, and (3) a substantial part of U_3O_8 production is purchased under long-term contracts which have cost escalation clauses, including cost increases due to regulations.

The model existing mill with the lowest cost increase for each case is a large mill with 15 years remaining lifetime and a small existing tailings pile. This model mill may be viewed as the industry price leader, in that existing mills will probably be unable to raise their prices above those of the least impacted mill and remain competitive. Alternatively, the cost increase for a new mill may also constrain the amount of the disposal cost that can be passed on to customers by existing mills since new mills will only be constructed and operated if they can cover all the costs of production. Therefore, we feel that the most likely potential price increase taking place as a result of tailings disposal will fall within the range of the production cost increases estimated for the least impacted model existing mill and the model new mill. This most likely price increase range is indicated for each impact case from the production cost estimates in Table 5.10.

Table 5.10. Range of Production Cost Increases across Model Mills by Economic Impact Case[(a)] (percents)

	Existing Mills		New Mill
Economic Impact Case	Model with Lowest Production Cost Increase	Model with Highest Production Cost Increase	Production Cost Increase
A	-	-	0.2
B_1	-	-	5.4
B_2	-	-	7.1
B_3	-	-	18.1
C	1.2	8.5	5.1
D	1.2	8.5	7.1
E	1.5	10.7	5.4
F	1.5	10.7	6.6
G	3.5	25.8	7.1
H_1	2.4	17.2	6.6
H_2	2.4	17.2	7.1
H_3	3.1	21.3	7.1
H_4	4.3	30.2	8.7
I	7.1	7.1	7.1
J	7.6	15.0	7.1
K	7.2	16.3	6.6
L	8.8	31.2	7.1
M_1	7.6	22.4	6.6
M_2	8.0	22.9	7.1
M_3	8.1	26.3	7.1
M_4	10.3	36.2	8.7
N	8.8	67.6	7.1

(a) Assumes a base production cost of \$30 per pound of U_3O_8.

Table 5.11. Range of Production Cost Increases across Economic Impact Cases by Model Existing Mill[a]
(percents)

	Size of Existing Tailings Pile								
	2 million MT			7 million MT			20 million MT		
	5 yrs	10 yrs	15 yrs	5 yrs	10 yrs	15 yrs	5 yrs	10 yrs	15 yrs
Small Mill									
Low	6.0	3.1	2.2	7.1	NA	2.9	NA	NA	NA
High	25.2	16.1	13.5	67.6	NA	24.8	NA	NA	NA
Medium Mill									
Low	3.3	1.9	1.4	NA	2.4	1.8	NA	NA	NA
High	16.9	12.4	11.1	NA	20.7	15.9	NA	NA	NA
Large Mill									
Low	NA	NA	1.2	NA	1.8	1.4	5.8	NA	2.1
High	NA	NA	10.3	NA	16.2	13.0	65.8	NA	24.2

[a] Assumes a base production cost of $30 per pound of U_3O_8.

NA = Not Applicable.

In cases where there are large increases in production costs, the competitiveness of the domestic industry with respect to foreign industry could be reduced and thereby lead to increased imports. Also, in the case of significant differential cost increases for small mills, this could lead to shifts in the size distribution of the industry away from smaller mills toward larger mills.

5.2.2.2 Mill Closures

For those cases where the production cost increases are substantial, part or all of the disposal costs may have to be absorbed by the mills. This could lead to closures of some mills. Assuming the conditions of a medium cash flow margin (20 percent) and no pass-through of the control costs, the number of mill closures may range from zero to as many as nine mills (5 small, 1 medium, 3 large) for Case N (see Table 5.4). Appendix A presents the complete mill closure results and includes variations in the cash flow margin and price pass-through assumptions.

In addition to the no pass-through scenario, we have analyzed the effects of two different levels of price pass-through on the mill closure analysis, a one dollar and a two dollar per pound increase in the price of U_3O_8. These limited pass-throughs of the disposal cost represent increases of 3.3 to 6.6 percent, assuming a base yellowcake price of $30 per pound. These price increases approximate the range in the production cost increases estimated for the least impacted model existing mill and the model new mill, as shown in Table 5.10. Therefore, these pass-through levels are reasonable representations of the average industry response to the requirements of the impact cases.

Table 5.12 presents the mill closure results by impact case for the three different assumptions on price pass-through: no pass-through, $1 per pound pass-through, and $2 per pound pass-through. The relationship between alternative degrees of price pass-through and the mill closure determination is evident from this table. The one small mill closure for Cases H_3, M_1, and M_2 is avoided with a $1 per pound pass-through. In Case M_3, the one small mill closure remains closed under each pass-through scenario. For Case G, closures are reduced from 2 small mill equivalents with no pass-through to zero with $2 per pound pass-through. For Case H_4, the four closures (small mill equivalents) are reduced to one at $2 per pound pass-through, while for M_4, the five closures are reduced to one. For the most costly case, N, the 16 small mill equivalents are reduced to only 13 with a $2 per pound pass-through.

5.2.2.3 Methods of Raising Capital

In some cases the disposal costs involve considerable sums of money. This may require firms in the industry to raise additional capital in order to meet these costs. Most of the firms in the industry are large corporations that will have access to a wide variety of financing alternatives and capital markets. Raising capital for pollution control expenditures is similar to raising capital for other expenditure programs;

Table 5.12. Mill Closure Results of Alternative Price Pass-Through Assumptions[a] (number of small mill equivalents)

Economic Impact Case	No Pass-Through	$1 Pass-Through	$2 Pass-Through
A	-	-	-
B_1	-	-	-
B_2	-	-	-
B_3	-	-	-
C	0	0	0
D	0	0	0
E	0	0	0
F	0	0	0
G	2	1	0
H_1	0	0	0
H_2	0	0	0
H_3	1	0	0
H_4	4	1	1
I	-	-	-
J	0	0	0
K	0	0	0
L	5	2	1
M_1	1	0	0
M_2	1	0	0
M_3	1	1	1
M_4	5	5	1
N	16	14	13

[a] Assumes baseline industry demand scenario and cash flow margin of 20 percent for each price pass-through scenario.

therefore, standard procedures for raising capital are applicable. Examples are the sale of common stock, corporate bonds, and commercial paper, or the firm can seek commercial bank loans. In some cases, the firms may be able to finance control expenditures with retained earnings.

5.2.2.4 Ability to Raise Capital

The ability to raise capital is dependent upon a firm's current and projected financial condition. If a firm is considering an investment that is projected to be profitable and it has a good credit rating based on past performance, capital generally will be available. Undoubtedly, some firms will find it easier to raise capital than will others. If an investment is not projected to be profitable, then there is no economic incentive to raise capital, even though the firm may have the ability to do so.

The financial condition of a firm can be assessed through a combination of factors. They include sales, profitability, liquidity, and leverage. Table 5.13 shows the sales for most of the existing firms in the industry. Sales are shown for the total company and the business segment within the company that includes the milling of uranium. The percentage of the company's total sales provided by the uranium milling segment is also shown. In some cases the uranium milling segment may also include other products. A company's total sales is one indicator of a company's ability to raise capital because larger companies are likely to have access to a broader range of methods to raise capital than smaller companies. The dollar volume of sales by the segment that includes uranium milling, together with the percentage of the company's total sales that are provided by this segment, are additional indicators of a firm's ability to raise capital. For example, if the uranium market is depressed and a firm depends on uranium milling for a high proportion of its business, then such a firm is more likely to experience difficulty in raising capital than another firm that is less dependent on uranium milling. In approximate terms, Table 5.13 suggests that, based on sales, there are two groups in the industry. One group has sales that are many billions of dollars, with a small percentage of those sales provided by uranium milling. The second group has sales that are considerably less than the first group and are relatively more dependent on uranium milling.

Another important measure of a firm's ability to raise capital is its debt in relation to its total capitalization, which is called leverage. If a firm has a high percentage of debt to total capitalization, then the firm has little leverage and is probably less able to raise new capital than is a firm with higher leverage. One method providing insight into a firm's ability to raise capital to pay for disposal costs is to estimate the change in a firm's long-term debt to total capitalization percentage that would result from these disposal costs, assuming that the cost is financed totally with debt.

Table 5.13. Sales for Companies in the Uranium Industry
($ in millions)

	Year	American Nuclear	Atlantic Richfield	Atlas	Conoco	Exxon	Federal Resources	Getty (Petrotomics)	Homestake
Total Company Revenues	1978	1.6	12,738.8	53.3	9,871.8	63,896.0	18.3	3,758.0	170.3
	1979	10.0	16,676.7	70.9	13,083.9	83,555.0	20.4	5,121.0	234.8
	1980	5.6	24,155.6	95.3	18,766.3	108,449.0	23.8	10,437.0	345.5
Uranium Segment Revenues	1978	.4		26.8	13.7				44.9
	1979	8.2		38.3	16.3				42.4
	1980	2.0		60.1	34.4				45.4
Percent Uranium Revenues/ Company Revenues	1978	23.4		50.4					26.4
	1979	82.3		54.0					18.1
	1980	35.1	< 1.0	63.1	< 1.0	< 1.0	100.0	< 1.0	13.1

	Year	Kerr-McGee	Newmont (Dawn)	Phelps Dodge (Western Nuclear)	Pioneer	Rio Algom[a]	Standard Oil of Calif. (Chevron)	Standard Oil of Ohio	UNC	Union Carbide
Total Company Revenues	1978	2,072.4	685.2	1,007.5	556.0	576.1	24,106.0	5,197.7	246.7	7,870.0
	1979	2,683.5	867.6		732.5	710.7	30,938.0	7,916.0	291.7	9,177.0
	1980	3,477.9	881.6		912.0	847.5	41,553.0	11,023.2	274.0	9,994.0
Uranium Segment Revenues	1978	115.2		43.0	13.8	153.1			133.2	
	1979	163.4	12.0		20.2	157.2			181.6	
	1980	238.9	14.7		7.8	225.9			167.8	
Percent Uranium Revenues/ Company Revenues	1978	5.6		4.3	2.5	26.6			54.0	
	1979	6.1	1.4		2.8	22.1			62.3	
	1980	6.9	1.7		0.9	26.7	< 1.0	< 1.0	61.3	< 1.0

[a] Canadian and U.S. operations.

Source: Companies' 1980 Annual Reports or from 1980 Form 10-K.

We performed a capital availability analysis for the individual companies in the uranium industry. The computation of the debt capitalization ratios, before and after control costs, forms the basis of this analysis. The difference in these ratios is an indication of the degree of difficulty each company might have in obtaining the necessary capital for tailings disposal. The companies are grouped according to their degree of difficulty, based on appropriate cutoff points. The analysis is explained below.

The starting point in the calculations begins with the no-control cost situation. The financial data used for this analysis is for the entire company, not just a subsidiary or a segment of the firm involved in the uranium business. By considering the resources of the entire company, a more realistic appraisal of the ability to raise capital is possible because the total financial resources of the firm can be used to secure credit. The parent corporation for each uranium mill is listed in Appendix D. The debt ratio is calculated for each company by dividing long term debt by its total capitalization (sum of long term debt and shareholders equity). This result represents the debt ratio before control costs. These ratios for 1981 are presented for each company in the first column of Table 5.14. An example of the calculation is as follows: The Atlantic Richfield Company (ARCO) shows long term debt of $3239.3 million in 1981 and shareholders equity of $8665.2 million. Total capitalization is, therefore, $11904.5 million. The debt ratio is 27.2 percent ($3239.3 million divided by $11904.5 million).

In order to estimate the impact of control costs for a specific firm, two assumptions were made. First, the control costs that are used are the existing tailings costs associated with the model mills -- they are not firm specific. The costs for each firm are those model pile costs that are applicable for the particular size of the tailings pile which we have estimated for each mill. Table A-3 in Appendix A lists the existing mills by the size of the tailings pile. Second, we assumed that the control costs occur entirely in a single year.

The control costs to be considered in this analysis are those associated with disposal methods ET3 and ET7. Method ET3 requires a 3-meter earth cover and rock cover on the slopes, while ET7 requires moving the existing pile and putting the tailings below grade with a liner and a 3-meter cover. Method ET7 is the most expensive control technique and represents a "worst case" scenario. These model pile costs (millions of 1981 dollars) are as follows:

	Tailings Pile Size		
Disposal Method	2 (10^6 MT)	7 (10^6 MT)	20 (10^6 MT)
ET3	6.9	11.4	22.3
ET7	12.3	43.7	126.9

Table 5.14. Capital Availability Analysis: Debt/Total Capitalization Ratios for Firms with Existing Tailings Piles

Consolidated Corp.	Before Control Costs (1) Debt/Total Capitalization 1981 (Percent)	Before Control Costs (2) Average(1) Debt/Total Capitalization (Percent)	After Control Costs (3) Debt/Total Capitalization for ET3 (Percent)	After Control Costs (4) Increase in Debt Ratio with Controls (ET3) (3)-(1)	After Control Costs (5) Debt/Total Capitalization for ET7 (Percent)	After Control Costs (6) Increase in Debt Ratio with Controls (ET7) (5)-(1)
Atlantic Richfield Co.	27.2	31.0	27.3	0.1	28.0	0.8
Atlas Corp.	35.7	30.9	44.8	9.1	60.6	24.9
Standard Oil of Cal. (Chevron)	8.4	12.3	8.4	0	8.5	0.1
Conoco, Inc.	23.1(2)	26.6(2)	23.2	.1	23.3	.2
Pioneer Corp.	31.6(2)	41.7(2)	32.5	0.9	34.9	3.3
Commonwealth Edison	54.1	53.2	54.1	0	54.1	0
Newmont Mining Corp.	10.7	15.1(3)	11.1	0.4	11.5	0.8
Exxon Corp.	15.3	15.9	15.4	0.1	15.4	0.1
Federal Resources Corp.	19.9(4)	7.5(4)	71.0	51.1	89.7	69.8
American Nuclear Corp.	56.8(4)	49.8(4)	64.3	7.5	76.1	19.3
Homestake Mining	.8	.4	7.7	6.9	30.4	29.6
Kerr-McGee Corp.	35.9	25.9	36.5	0.6	39.2	3.3
General Electric Co.	10.4	12.7	10.6	0.2	11.2	0.8

Table 5.14. Capital Availability Analysis: Debt/Total Capitalization Ratios for Firms with Existing Tailings Piles (continued)

	Before Control Costs		After Control Costs			
Consolidated Corp.	(1) Debt/Total Capitalization 1981 (Percent)	(2) Average(1) Debt/Total Capitalization (Percent)	(3) Debt/Total Capitalization for ET3 (Percent)	(4) Increase in Debt Ratio with Controls (ET3) (3)-(1)	(5) Debt/Total Capitalization for ET7 (Percent)	(6) Increase in Debt Ratio with Controls (ET7) (5)-(1)
Getty Oil Co.	11.8	8.2	11.9	0.1	12.0	0.2
Rio Algom Limited	16.8	21.9	17.8	1.0	18.5	1.7
Union Pacific Corp.	35.4	29.7	35.5	0.1	35.7	0.3
Southern Calif. Edison Co.	48.2	49.0	48.3	0.1	48.4	0.2
Standard Oil Co. (Ohio)	36.9	54.5	36.9	0	36.9	0
Reserve Oil & Minerals Corp.	1981: Neg(5) net worth	9.9(5)	60.6(5)	50.2	73.4	63.0
Union Carbide Corp.	28.5	29.6	28.8	0.3	29.4	0.9
UNC Resources, Inc.	26.7	34.1	28.9	2.2	30.4	3.7
Phelps Dodge	34.7	38.5	35.4	0.7	36.9	2.2

(1) The average ratio represents a five year average from 1977 to 1981 except if noted otherwise.

(2) The debt ratio is for the year 1980 and the average is for the period 1976 to 1980. In 1981 Conoco was acquired by DuPont.

(3) The average represents the three year period from 1979 to 1981.

(4) The debt ratio is for the year 1982 and the average represents the four year period, 1979 to 1982.

(5) Reserve Oil and Minerals Corp. showed a large loss for 1981 which resulted in a negative net worth position. The average debt ratio represents a two year period, 1979 and 1980. Data prior to 1979 are not available. The financial data used as the basis for the after control costs ratios are from 1980. The calculation of the increase in the ratio with controls uses the average debt ratio as the base.

In order to compute the debt ratio after control costs, the costs of control must be added to both the debt amount and to total capitalization. As an example, for ARCO, using the controls associated with ET3, it can be seen from Table A-3 that the Anaconda (a subsidiary of ARCO) pile is of the 20 million metric ton size and has control costs of $22.3 million. This amount is then added to the debt amount of $3239.3 million, resulting in $3261.6 million. The total capitalization is now $22.3 million plus $11904.5 or $11926.8 million. Dividing $3261.6 million by $11926.8 million results in 27.3 percent, or an increase of 0.1 percent in the no-control debt ratio. In this particular case, because ARCO is such a large company, the addition of the control costs causes a very small impact on ARCO's debt level. The results of these calculations are shown in column (3) of Table 5.14 while column (5) presents the debt ratios using ET7 as the basis for control. Three companies, Union Carbide, Exxon, and Western Nuclear (Phelps Dodge), each have two mills, so the appropriate control costs are summed for the two mills and then added to the no-control values. For mills that are jointly-owned by two companies, the control costs were split equally and assigned to each company.

The results of these calculations can be better understood by examining the change in the ratios due to tailings disposal costs. These differences are shown in columns (4) and (6) as percentage point changes. It is also helpful to compute an average debt ratio over a period of five years in order to eliminate the effect of an unusually low or high value for any given year. Such an unusual value does represent the financial situation of a firm for that particular year, but may not represent the norm. An average value smooths out these aberrations, the results of which are shown in column (2).

After examining the results of Table 5.14, it is possible to divide the companies into three groups, according to the degree of difficulty that they would have in obtaining capital. The first group consists of those firms who would experience little or no difficulty in obtaining the necessary capital. Their debt ratios increase by less than five percentage points, and their debt ratios with controls are below 40 percent. The second group of companies may have some difficulty in raising the required capital as their debt ratios increase significantly in either absolute amounts or compared to historical levels. The firms in the third group are having financial problems and would probably be unable to raise the necessary capital. This grouping of companies is shown in Table 5.15.

The cutoff points of a five percentage point difference in the debt ratio and the 40 percent debt ratio level have been derived by examining the financial data of the firms in the industry over the last five years. It is evident that for most firms in the industry the debt ratios are below 40 percent and the addition of control costs causes the debt ratio to increase by less than five percentage points. A historical review of

Table 5.15. Capital Availability Analysis: Grouping of Firms by Degree of Capital Availability Problems (percentage points)(a)

GROUP 1: Minimal or No Impact in Meeting either ET3 or ET7	Increase in Debt Ratio with Controls (ET3)	Increase in Debt Ratio with Controls (ET7)
Commonwealth Edison	-	-
Standard Oil Co. (Ohio)	-	-
Standard Oil of Cal. (Chevron)	-	.1
Exxon Corp.	.1	.1
Getty Oil Co.	.1	.2
Southern Calif. Edison Corp.	.1	.2
Conoco, Inc.	.1	.2
Union Pacific Corp.	.1	.3
Atlantic Richfield Co.	.1	.8
General Electric Co.	.2	.8
Newmont Mining Corp.	.4	.8
Union Carbide Corp.	.3	.9
Rio Algom Limited	1.0	1.7
Phelps Dodge	.7	2.2
Kerr-McGee Corp.	.6	3.3
Pioneer Corp.	.9	3.3
UNC Resources	2.2	3.7
GROUP 2: Some Difficulty in Meeting ET3 and Significant Problems in Meeting ET7		
Atlas Corp.	9.1	24.9
Homestake Mining	6.9	29.6
GROUP 3: Significant Problems in Meeting Either ET3 or ET7		
American Nuclear Corp.	7.5	19.3
Reserve Oil & Minerals Corp.	50.2	63.0
Federal Resources Corp.	51.1	69.8

(a) Percentage point changes are taken from Table 5.14.

- = negligible impact (below .1 percentage points).

the financial data shows that changes of about five percentage points are not uncommon. Those firms that exceed these limits generally do so to a great degree so that this cutoff point appears to clearly divide the firms according to impact.

The majority of the companies fall into the first group, with minimal or no impact as a result of either disposal method. These companies are for the most part very large diversified firms. The increase in the debt ratio with controls (either ET3 or ET7) is readily manageable, generally less than five percentage points. The debt ratios for these firms do not exceed 40 percent in either case, a level generally considered to be reasonable. The two utility companies, Commonwealth Edison and Southern California Edison, have ratios that exceed 40 percent before controls. However, because utility companies have a stable revenue stream, they are able to incur relatively high levels of debt. Therefore, these debt ratios can be considered as typical of their industry.

One company in Group 1 may be more affected by the control costs than the other companies. The Kerr-McGee Corporation shows a much higher debt ratio with controls than their average debt ratio. As presented in Table 5.14, their 1981 debt ratio of 35.9 percent is significantly greater than their average ratio of 25.9 percent. This situation arises because, prior to 1981, the debt ratio ranged from 19 to 28 percent. In 1981, Kerr-McGee increased their amount of debt by 60 percent from the prior year, resulting in a debt ratio of 35.9 percent. Therefore, we believe that a debt ratio of either 36.5 percent (ET3) or 39.2 (ET7) can be undertaken by the company.

The two companies in Group 2 may have difficulty in obtaining the necessary capital, but for different reasons. Homestake Mining Co. has had a strong profitability record during the past five years, and they have used almost no long term debt. Their highest debt ratio was in 1981 and it was extremely small, 0.8 percent. They have a large tailings pile which would result in debt ratios of 7.7 percent for ET3 and 30.4 percent for ET7. Although these debt ratios are roughly the same as, or below, many companies in the industry, for a company that has historically preferred to carry very little debt, the financial community may hesitate to extend this level of debt. This situation is considerably more relevant to the higher level of financing associated with ET7 than with ET3. However, an examination of their financial statements shows that a significant portion of the control costs could be financed with retained earnings, which would reduce their need for external financial markets. It should also be noted that Homestake's major activity is gold production. Therefore, their financial health rests mainly on the status of the gold market. Assuming that the company's financial outlook remains good, by using a combination of retained earnings and debt, they should be able to obtain the necessary capital. The Atlas Corporation presents a different situation. Their debt ratio changes from a no-control ratio of 35.7 percent to 44.8 percent with ET3, and 60.6 percent with ET7. Both of these debt levels are high, particularly the ratio associated with ET7. A debt ratio of 60 percent would be excessive for extremely profitable companies. This level of debt has not been experienced by any firms in this industry in recent years and is simply not a financially viable situation. Atlas has had an uneven earnings history over the past five years with a net loss in 1979, and the major segment of their business is uranium, which is currently in a period of contraction. Therefore, this level of debt is not feasible, and even the lower level of 44.8 (ET3) may present difficulties, although the company was almost at this debt level in 1980 when it reached 44.5 percent.

The last group, Group 3, consists of three companies, all of which are experiencing financial difficulties even in the absence of control costs. Their financial difficulties are made worse by the addition of control costs. These companies, American Nuclear, Federal Resources, and Reserve Oil and Minerals, derive their major source of revenues from the production of uranium and have been directly affected by the declining uranium market. Federal Resources and American Nuclear, partners in the Gas Hills, Wyoming, mill, have experienced net losses during fiscal 1982 (Federal Resources had a net loss in 1981 as well) and both had declines in sales from the previous year. Reserve Oil and Minerals Corp. has had net losses for three consecutive fiscal years, 1979 through 1981. During fiscal year 1981 they also had negative net worth. Reserve Oil is a partner with the Standard Oil Company of Ohio in the Seboyeta, New Mexico, mill. For all three companies, the impact of control costs results in excessively high debt ratios as shown in Table 5.3. These companies are in such poor financial health that any significant amount of external financing is not feasible, and financing by retained earnings is also impossible.

5.2.3 Regional Impact

In Chapter 2, we stated that uranium mining and milling occurs in the western States of Colorado, New Mexico, Texas, South Dakota, Utah, Washington, and Wyoming. Therefore, the economic impact of controls will be concentrated in western United States. The economic impacts associated with a mill closure depend on the characteristics of the site and the region where the mill is located. In our generic analysis, we have not identified specific mills that are subject to potential closure due to the EPA standards. Consequently, it is impossible to accurately estimate the extent of the impacts that could arise. Nevertheless, we analyzed the regional impact by using a model region. We assumed a model region that is characteristic of the regions where the mills are located. The model region is likely to differ, in some characteristics, from any specific actual region. The boundary defining the area receiving the majority of the potential economic impact is an 80 kilometer (50 mile) radius around the mill.[25] Table 5.16 describes the population characteristics of the model region, broken down into two subregions - a circular inner subregion with a 40 kilometer radius around the mill, and an outer ring from 40 to 80 kilometers around the mill. Table 5.17 describes the assumed economic characteristics of the region. The regional impact estimation procedure assumes that mill closures due to control costs are permanent, although, as described in Appendix B, there are some mills that may close temporarily based on market conditions and then reopen when market conditions improve.

Table 5.16. Demographics of the Model Uranium Mining and Milling Region

	Distance from Mill (Km)	Area (Km^2)	Population		% Increase 1960-1976	Current Labor Force
			1960	1976		
Inner Subregion	0-40	5,000	1,920	2,200	15	-
Outer Subregion	40-80	15,000	47,560	55,100	16	-
Total Region	0-80	20,000	49,480	57,300	16	20,800

Source: U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, September 1980.

Table 5.17. Economic Characteristics of the Model Region

Industrial Sector	% Employed By Sector[a]	Sector Employment	Sector Payroll[b] (million $)
Manufacturing	5.0	1,040	15.23
Wholesale and Retail Trade	18.7	3,890	46.93
Government	21.8	4,534	55.26
Services	13.1	2,725	32.42
Transportation and Public Utilities	7.5	1,560	28.07
Finance, Insurance, Real Estate	3.0	624	7.33
Contract Construction	8.8	1,830	36.58
Mining	11.2	2,330	43.38
Agriculture	10.9	2,267	37.20
Total	100.0	20,800	302.[illegible]0

[a] Source: U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, September 1980. The original NRC distribution was adjusted to include agriculture.

[b] Sector payroll equals average wage in sector times sector employment. Average wage was obtained from U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States, 1980.

If mill closures occur, the potential impacts include reduced employment, reduced tax receipts, and reduced property values. The effects of a mill closure go beyond the loss of employment at the mill and the revenues of the mill, for they have repercussions on the economy of the region. The total economic impact of mill closures on a region is composed of three effects: direct, indirect, and induced effects. The direct effects include the employment at the mill, the revenue of the mill, and the taxes paid by the mill. The indirect effects are the reduced expenditures by other businesses for materials used in the production process. The induced effects are reduced expenditures made by all households for final goods and services, which reduces the level of commerce in the entire region, and to a minor extent, commerce outside the region.

The direct effects of any particular impact case can be estimated by reviewing the number of model mill closures associated with the case and summing the effects for each closure. For example, if lost employment due to model mill closures is of interest, and three model mills are projected to close, then the direct loss of employment is simply the sum of the employment for the three model mills. The total employment effect (direct, indirect, and induced) can be estimated by applying a multiplier to the direct effect. Multipliers are developed for estimating the total economic impact on a region resulting from a change in income or employment in a specific industry. The values assumed for a multiplier may change according to the characteristics of the region and the industry investigated. A multiplier of 2.21 is used to represent the total impact on employment and 1.97 to represent the total impact on payroll earnings in the Western United States(EMJ81).

The impacts on employment and payroll in the model region are presented in Table 5.18. The direct impacts on employment resulting from a mill closure range from a decrease of 70 employees for a small model mill to 210 employees for a large model mill. Total employment impacts range between 155 and 464 employees resulting from the closure of a small or large model mill, respectively. Because of the relatively small size of the work force in the model region, the unemployment rate will be impacted significantly, with a range of increases in the rate from 0.7 to 2.2 percent, depending on the size of the model mill closure.

The total impact on the region's payroll ranges between $3.2 million and $9.5 million, depending upon the size of the model mill. In relative terms, the impact on the region's payroll is larger than the impact on the region's work force, ranging from a decrease of 1.1 to 3.2 percent. This larger impact on the area's payroll is due to the larger than average wages and salaries received by the employees in the uranium mining and milling industry.

Table 5.18. Direct, Indirect, and Induced Impacts on the Model Region Resulting from a Single Model Mill Closure

Model Mill	Model Mill Size (MT)	Mill Employees[a]	Total Impact on Work Force[b]	% of Region's Work Force	Total Mill Payroll (Million $)[c]	Total Impact on Payroll (Million $)[d]	Percent of Area Payroll
Small	907	70	155	0.7	1.6	3.2	1.1
Medium	1,814	140	309	1.5	3.2	6.3	2.1
Large	2,721	210	464	2.2	4.8	9.5	3.2

[a] This cross-section of model mills assumes no economies of scale with respect to the utilization of labor. Employees per metric ton of capacity was calculated using data from U.S. Department of Energy, Statistical Data of the Uranium Industry, 1980. Mill employees equals model mill capacity times employees per metric ton of capacity.

[b] Mill employees times 2.21.

[c] Total mill payroll equals mill employee times average yearly salary per employee. Salary per employee was obtained from U.S. Department of Commerce, Bureau of the Census, Census of the Mineral Industries, 1977.

[d] Total mill payroll times 1.97.

Additional short-run impacts on the region would include reduced tax receipts, reduced property values, and reduced personal income. However, over the long-run, these short-run problems should be mitigated as the regional economy adjusts to the mill closures and returns to equilibrium. Long-run transition mechanisms that restore equilibrium include the mobility of the work force and the influx of new industry.

5.2.4 Macroeconomic Impact

The impacts discussed in previous sections are also applicable at the macroeconomic level. However, most of these impacts will have minor impact at this level. As a result, these effects may be difficult, or even impossible, to discern. For example, even though the potential employment losses may be significant for the uranium industry and significant for a particular region under some cases, the effect on the national unemployment rate is not likely to be perceptible. One potential impact that may be discernible at the national level is imports of uranium.

For the most costly impact case, there is the potential that nine model mills will close (5 small, 1 medium, 3 large). These nine model mills represent about 4800 metric tons of U_3O_8 capacity, or about 27 percent of total 1980 industry capacity of 18,000 metric tons. If the market price for yellowcake is depressed so that it is not economical for new mills to replace this capacity, imports may replace lost domestic production.

An increase in the imports share of the domestic market, to about 30 percent, by 1985 seems possible given the results of a recent study by Nuclear Resources International (NRI81). That report estimates that the average penetration of imports into the domestic market assuming no import controls would range from 22 to 23 percent during the period 1983-1990. An upper boundary for foreign uranium purchases is estimated to be approximately 31 percent. This 31 percent limit suggests that domestic utilities would consider purchasing a maximum of 31 percent of their requirements from foreign producers. As described in Chapter 2, some domestic utilities may not wish to purchase that much uranium from foreign producers because foreign sources of supply are less certain than domestic sources of supply. (For the 1991-2000 period, an average purchase limit of about 36 percent is estimated to be an upper boundary.) Even under our worst-case scenario of nine model mill closures, production from the lost domestic capacity could be substituted by the additional use of imports without exceeding the 31 percent upper boundary.

We cannot estimate the impact of tailings disposal costs on imports of uranium for several reasons. First, the ban on imports from 1964 to 1976 prevents any attempt at analysis using past behavior to predict future behavior. Therefore, we cannot estimate the domestic demand elasticity for imports.

Second, the precise nature of the monopolistic power wielded by foreign governments is not known. Even though several foreign countries already have significant comparative cost advantages in the production of uranium, import prices do not always reflect the lower costs.

A final consideration with respect to imports and the maintenance of a viable domestic uranium industry is the subject of national security. Undoubtedly, the existence of a domestic source of supply of uranium implies a more stable source of supply than does a substantial reliance on imports. Evidence of the importance of this consideration is provided by the existence of the current restriction on imports.

5.2.5 Government Subsidy

The Federal and State Governments have assumed the financial responsibility for reclamation of tailings piles at all inactive uranium mill sites under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). The apparent reason for their assuming financial responsibility was that the mills at these sites had been operating under contracts with the Federal Government, primarily for supplying uranium to be used for defense purposes. UMTRCA was enacted into law after the life cycles of those mills had been completed, leaving no opportunity for tailings disposal control costs to be recovered through product price increases. If tailings control requirements had been imposed earlier, the mill owners would have been able to pass the control costs to their customers, i.e., the Federal Government. Thus, the government would have ultimately paid the control costs.

Many of the active mills also operated under contracts with the Federal Government between 1943 and 1970. Therefore, some of the existing tailings inventories at these sites also resulted from government contracts. The tailings resulting from these government contracts are referred to as being commingled with the tailings resulting from the mills' commercial business. The Department of Energy National Defense Programs Authorization Act of 1981 authorized DOE to assess the commingled tailings situation and report back to Congress by October 1981 with recommendations for dealing with them. DOE submitted this report to Congress in June 1982 (DOE82).

According to the DOE study, commingled tailings are located at 13 licensed mill sites. As of the end of 1981, there were approximately 125 million MT (138 million short tons) of tailings at these 13 sites, of which about 51 million MT, or 41 percent, are believed to be defense related. The DOE estimate of defense-related tailings represents about 35 percent of all the tailings which we estimate have accumulated at all the licensed mills as of January 1980 (see Table 2-10).

Efforts are underway in Congress to provide financial assistance to mill owners whose sites contain commingled tailings. These efforts are based on the grounds that since the Federal Government agreed to pay for the stabilization of tailings at inactive sites which resulted from government contracts, the government should help pay for the stabilization of tailings at active sites which also resulted from government contracts. Whether or not a subsidy is justified has no effect on the development of the EPA standards and, therefore, is not discussed in this

RIA. However, we have estimated the potential size of a subsidy for the different economic impact cases based on our tailings disposal cost estimates and DOE's estimate of the quantity of tailings resulting from government contracts.

To determine the amount of the subsidy for each case, we multiply an appropriate unit cost of disposal ($ per ton of tailings) by the 51 million MT of defense-related tailings estimated by DOE. The unit cost is derived by dividing our total cost estimates for disposing of all 23 existing tailings piles (from Table 5.2) by the estimated total quantity of tailings at these piles, 146 million MT. These estimates are presented in Table 5.19. Ignoring the no disposal cases (A, B, and I), the subsidy estimates range from 44 million dollars for Cases C and D to 329 million dollars for Case N.

Since the EPA standards are indifferent toward the establishment of a subsidy program, we have not investigated the ways in which such a program could be implemented. Also, we have not analyzed the impact that subsidies would have on the individual mills. If a subsidy program is implemented for the sites with commingled tailings, then the economic impacts resulting from tailings disposal would be diminished for those sites.

Table 5.19. Subsidy Estimates for Commingled Tailings By Economic Impact Case (millions of 1981 dollars)

Economic Impact Case	Amount of Subsidy
A	---
B_1	---
B_2	---
B_3	---
C	44
D	44
E	53
F	53
G	140
H_1	87
H_2	87
H_3	106
H_4	154
I	---
J	44
K	53
L	140
M_1	87
M_2	87
M_3	106
M_4	154
N	329

REFERENCES FOR CHAPTER 5

DOE82	U.S. Department of Energy, Commingled Uranium Tailings Study, Volume I, Plan for Stabilization and Management of Commingled Uranium Mill Tailings, DOE/DP-0011, June 30, 1982.
EMJ81	Engineering and Mining Journal, "Can Changes be Made that Will Encourage Mine Development?" May 1981.
NRI81	Nuclear Resources International, "Domestic Utility Attitudes Toward Foreign Uranium Supply," prepared for the U.S. Department of Energy, Grand Junction Office, Contract No. DE-AC13-76GJ01664, June 1981.

6. Selection of Proposed Standards

There are two major parts of the proposed standards, as discussed in Chapter 1: control of releases from tailings during processing operations and permanent control of tailings through final disposal. Since most of the requirements for operations are already in existence, through regulations promulgated under the AEA, the CWA, and the SWDA (as required under the Act), alternative standards for operations are not considered in this analysis. However, these existing standards (which are supplemented in these proposed standards by a few additional criteria specific to uranium tailings) are summarized in section 6.1 to show that all identified environmental threats from tailings are or will be controlled.

Our rationale for selecting the proposed standards for disposal is presented in section 6.2. The selection is based on material presented earlier in this RIA and on information contained in the EIS.

6.1 Operations Standards

Particulate Emissions

Radioactive particulate emissions from uranium mill tailings piles during the operational phase of the mill are currently controlled by EPA's Uranium Fuel Cycle Standards (40 CFR Part 190). These standards limit the annual radiation dose to members of the public to 25 millirem to the whole body or any organ (except the thyroid, which is limited to 75 millirem) as a result of discharges to the general environment from uranium fuel cycle operations. Uranium mills, including the tailings piles, are included in uranium fuel cycle operations, as defined in the standards.

We have reviewed the adequacy of these standards as they relate to uranium mill tailings piles and conclude that additional standards under the Act are not warranted. We considered the need for more stringent standards, but conclude that the benefits do not justify the additional costs to meet such standards and that determination of compliance with standards at lower dose levels could be difficult and costly. We also considered a less stringent standard and conclude that, since control methods are available at reasonable costs to meet the current standards, there is no justification for raising the standards to higher levels.

Radon Emissions

Control of radon emissions from uranium mill tailings are not currently included in EPA standards. Radon and its decay products were excluded from 40 CFR Part 190 because at that time considerable uncertainty existed about the feasibility of controlling radon emissions from tailings piles. EPA concluded that the problems associated with controlling radon emissions were sufficiently different from those of other radionuclide emissions associated with the uranium fuel cycle to warrant separate consideration at a future time. Radon concentrations in air in unrestricted areas resulting from emissions from uranium mill tailings are currently limited by NRC's Standards for Protection Against Radiation (10 CFR Part 20). These standards, which are derived from the Federal Radiation Protection Guidance (25 FR 4402), limit the radon concentration in air in areas to which individual members of the public have access to 3 pCi/l. Areas in which unlimited permanent residence by large numbers of people is possible are limited to one-third of this value, or 1 pCi/l, by Federal Radiation Protection Guidance.

Practical methods for significantly reducing radon emissions during the operational phase of existing mills are limited in their effectiveness to about a factor of 3 reduction; the exact degree depends strongly on specific characteristics of the tailings management scheme appropriate for a given site. Control can be achieved by keeping the tailings wet (usually with process liquids) or by covering portions of the pile not in active use with earth.

The incremental increase in the working level concentration in houses caused by 1 pCi/l of radon in air is about 0.005 WL. Such an increase over a 15-year period (the operational period of the model mill) would cause an increase in the lifetime risk of lung cancer of 1 in 1,000. Although such incremental risks are not insignificant, they are only about 25 percent of the average risk to individuals from natural radon sources, and only a very few individuals would be exposed to these levels. Based on all of the above, we have concluded that a more restrictive radon standard than now exists for the operating phase of a mill is not justified. The regulatory agency should assure, under the Federal Radiation Protection Guidance, that exposure to radon emissions is minimized as far below existing limits as is practicable, through the choice of tailings management procedures and site boundaries.

Discharges to Surface Waters

Wastes are currently discharged to surface waters at only one site. Such discharges are not necessary in most uranium mining regions because annual natural evaporation is greater than precipitation. Liquid wastes can therefore be stored in a pond, lined to prevent seepage into groundwater, and allowed to evaporate.

EPA is continuing to implement the requirements of the Clean Water Act. EPA's programs for new source performance standards (NSPS) are now aimed principally at control of toxic pollutants. Regulations are now in effect which define best practicable technology (BPT) for wastewater discharges from existing mills and new source performance standards (NSPS) for control of discharges from new mills using the acid leach, alkaline leach, or combined acid and alkaline leach process for the extraction of uranium (40 CFR Part 440). As an example of these regulations, the NSPS require that "There shall be no discharge of process wastewater from mills using the acid leach, alkaline leach, or combined acid and alkaline leach process for the extraction of uranium or from mines and mills using in-situ leach methods."

In view of the comprehensive regulatory program in place for surface water discharges from the uranium milling industry, we believe no additional standards for surface water are needed under this Act.

Groundwater Protection

The Act requires that the standards proposed herein for nonradiological hazards protect human health and the environment in a manner consistent with the standards required under subtitle C of the Solid Waste Disposal Act (SWDA), as amended (Section 275b(2)). The Act also directs the NRC to regulate in conformance with the SWDA (Section 84a(3)). This section directs the NRC to "...insure that the management of any uranium tailings conforms to general requirements established by the Commission, with the concurrence of the Administrator, which are, to the maximum extent practicable, at least comparable to requirements applicable to the possession, transfer, and disposal of similar hazardous material regulated by the Administrator under the Solid Waste Disposal Act, as amended."

Standards for nonradiological hazards under subtitle C of SWDA are part of a comprehensive regulatory program to protect human health and the environment from hazardous waste disposal in or on the land. This program includes identification and listing of hazardous materials, a manifest system to track hazardous materials from cradle to grave, controls for the transportation of hazardous materials, standards for owners and operators of hazardous waste treatment, storage and disposal facilities, and a permitting system for the treatment, storage and disposal of hazardous waste. EPA's role for control of hazardous materials from uranium tailings under this Act is limited to setting standards and does not include a regulatory responsibility. That responsibility is vested in the NRC and the States as the licensing agencies under Title II of the Act.

The purpose of the SWDA groundwater protection regulations is to assure that groundwater quality is compatible with the various uses to which it may be put, so that reasonable assurance exists that human health and the environment will be protected. To accomplish this, the fundamental goal of the regulations is to minimize the migration into the environment of the hazardous component of the waste placed in land disposal units. EPA's strategy for achieving this goal has two basic elements. The first element is a liquids management strategy for disposal units that is intended to minimize leachate generation in the waste management units and to remove leachate from these units before it enters the subsurface environment. This is the "first line of defense" in the sense that it seeks to prevent groundwater contamination by controlling the source of the contamination. The second element of the general strategy is a groundwater monitoring and response program that is designed to remove leachate from the groundwater if it is detected. The monitoring and response program serves as a backup to the liquids management strategy and would be established by regulations set by the NRC, with the concurrence of the Administrator, upon promulgation of these standards by EPA.

The standard proposed here to carry out the first element of the groundwater protection strategy is contained in Subpart K of existing SWDA regulations, at 40 CFR Section 264.221, which applies to surface impoundments. This section requires a liner that is designed, constructed, and installed to prevent migration of wastes out of the impoundment to the adjacent subsurface soil, or groundwater, or surface water during the active life (including the closure period) of the impoundment. Under this section, an exemption to the requirement for a liner may be granted if the owner or operator demonstrates that alternate design and operating practices, together with location characteristics, will prevent the migration of any hazardous constituents into ground or surface water. This section also exempts the pre-existing portion of an impoundment from the liner requirement. The existing portion is defined as the land surface area on which wastes (in this case, tailings) have been placed prior to the effective date of the regulations.

Two points are important here. First, by providing an exemption procedure to the liner requirement, EPA recognized that adequate groundwater protection can be achieved at some locations without a liner. An example of a situation for which this exemption may be appropriate is one where: (1) the unsaturated zone below the impoundment is composed of materials that are capable of attenuating any hazardous constituents in the process liquid before it reaches ground or surface water (e.g., holding up hazardous constituents through ion exchange); (2) the tailings are located in an arid area in which precipitation does not recharge groundwater; and/or (3) the quantity of wastes is very small.

Second, the requirement for a liner does not apply to the land surface areas where tailings are currently placed. This means that a liner would usually not have to be installed under existing tailings. This is consistent with our economic analysis which indicates that installing liners under existing tailings is usually not cost effective. Further, depositing tailings on existing piles could continue as long as the pile surface area is not expanded and limiting concentrations of hazardous constituents are not exceeded in groundwater. However, any expanded portion of an existing impoundment would be subject to the same liner requirements (or their equivalent) as a new impoundment. If hazardous constituent concentration limits exceed the groundwater standards, continued deposition of tailings on an existing pile may or may not be permissible, depending on the effectiveness of the corrective action program or the result of a decision to seek an alternate standard or an exemption.

Finally, the proposed standard exempts uranium byproduct material impoundments from the surface closure requirements of Section 264.228. This modification is proposed since the proposed standards for disposal of tailings (Section 192.32(b)) are adequate to protect groundwater. The considerations involved are discussed in more detail below.

In summary, EPA proposes here a primary groundwater protection requirement to prevent seepage of leachate from the tailings into groundwater. This is consistent with the primary groundwater protection standard specified in the SWDA regulation, where such a standard is identified as a "technical performance" standard. In many cases, this may require installation of a liner under the tailings. However, a liner is not required if an equivalent level of protection can be achieved through the selection of a tailings impoundment location.

The standard proposed here to carry out the second element of the groundwater protection strategy is also contained in existing SWDA regulations, at 40 CFR Section 264.92. This standard specifies two additional parts. The first part is contained in Section 264.93 and identifies hazardous constituents as those listed in Appendix VIII of Part 261. We propose to add two hazardous chemical elements, molybdenum and uranium, commonly present in tailings. The second part is contained in Section 264.94 and requires that "...no increase over background levels" be allowed for most listed constituents. This approach is consistent with a groundwater protection philosophy that seeks to maintain groundwater quality for any current or future uses. The second part also contains Table 1 - "Maximum Concentration of Constituents for Groundwater Protection." These standards are maximum concentration limits for a particular set of toxic metals and pesticides and were first established in the National Interim Primary Drinking Water Regulations (NIPDWR) as health-based concentration limits. We propose to add to these limits the corresponding NIPDWR limits for the radioactive materials found in tailings.

These proposed standards would require the measurement of background concentrations of hazardous constituents in groundwater at each tailings site. Background concentrations would be measured only for those hazardous constituents that are reasonably expected to be in or derived from the tailings. The standards would then be established for most constituents at the background groundwater concentrations. The maximum concentrations listed in Table 1 of Section 264.94 of this chapter and the maximum concentrations of radioactive materials listed in Table A of the proposed standards would be established as standards if these concentrations are greater than the background concentrations. If background concentrations are greater than the Table 1 and Table A concentrations, the standards would be established at the background concentrations.

The SWDA standards allow the Regional Administrator to exclude a hazardous constituent from the list of hazardous constituents applicable to a site if he finds that the constituent is not capable of posing a substantial present or potential hazard to human health or the environment (Section 264.93(b) and (c)). He is also allowed to establish an alternate concentration limit for a hazardous constituent if he finds that the constituent will not pose a substantial present or potential hazard to human health or the environment as long as the alternate concentration is not exceeded (Section 264.94(b) and (c)). EPA believes that determinations as to what constituent levels pose a health hazard are a primary responsibility of EPA and cannot be delegated to other agencies. Therefore, we propose to retain effective control over granting of exemptions and establishment of alternate standards for groundwater by requiring EPA concurrence in regulatory decisions regarding such exemptions and alternate standards.

Section 264.100 of the SWDA regulations requires that a corrective action program be initiated when hazardous constituent concentration limits are exceeded in groundwater. However, the time within which this corrective action program is to be initiated is not specified. We propose to require this corrective action program be initiated within one year, if such a program is needed. A restriction on the period for beginning corrective actions is reasonable for tailings sites since there are less than 30 licensed sites all containing similar materials. The SWDA regulations require only that corrective actions begin within a reasonable time period. However, the SWDA regulations are applicable to thousands of sites, with a wide variety of hazardous constituents.

6.2 Disposal Standards

6.2.1 Form of the Standards

Standards can be in the form of engineering specifications, design considerations, performance requirements, or ambient environmental levels. Engineering standards for tailings disposal would likely specify the type and minimum thickness of earthen cover to be used for disposal. EPA is precluded from issuing engineering standards for uranium byproduct material in the legislative history of the Act. The Report (on the Act) of the Committee on Interior and Insular Affairs, U.S. House of Representatives (U.S.78), states, "The EPA standards and criteria should not interject any detailed or site-specific requirements for management, technology, or engineering methods on licensees..."

Performance standards specify the level of control that must be achieved, but do not specify how the level is to be achieved. They often take the form of release rate limits, but can be stated in concentration limits of air or water if the pathway through the environment is adequately known.

Design standards specify what is to be achieved by control methods. They guide the design of control methods without specifying engineering requirements and thus allow creativity and initiative to be used in providing control methods. They often take the form of requirements which cannot be precisely measured and must be calculated. An example of a design standard is specifying the minimum number of years that controls must be effective.

General ambient standards usually take the form of a concentration limit in air or water. They can also take the form of a radiation dose limit to humans since radiation dose can be directly related to ambient concentrations.

After consideration of the available forms, we conclude that a standard specifying release rate limits of radon to the atmosphere is the form most likely to accomplish the goals of the disposal standard. These goals are presented in Chapter 3.

Release rate limits for radon can be directly related to the thickness of earthen cover material - the primary control technique assumed in this RIA - by using Figure 3.1. The radon emission rate for new tailings with no controls was estimated as 280 pCi/m^2s by the NRC (NRC80). This value can also be used for existing tailings since more recent processing of lower grade ores would result in a release rate of about 280 pCi/m^2s from the top of the pile where the more recently generated tailings are deposited.

Using Figure 3.1 and the uncontrolled radon source term of 280 pCi/m^2s, we conservatively estimated the release rates for the disposal methods:

thickness of earth cover (m)	radon control achieved for 1,000 years (%)	radon release rate (pCi/m^2s)
0.5	50	150
1	80	60
3	95	20
5	> 99	2

These are conservative estimates since they reflect an average soil with no compaction. In practice, we anticipate that greater levels of radon control may be achieved than indicated for the various cover thicknesses. The period over which the indicated control is achieved is 1,000 years. Thus, the percent of radon control indicates control of that fraction of the total radon emissions expected over 1,000 years if no control measures are taken.

By specifying a radon release limit that would require a thick cover, e.g., about 3m of earth, we would also fulfill the other objectives discussed in Chapter 3. This is discussed in detail in the next section.

6.2.2 Level of Control

The objectives of tailings control and stabilization efforts are to prevent their misuse by man, to reduce radon emissions (and gamma radiation exposure), and to avoid the contamination of land and water by preventing erosion by natural processes. The longevity (i.e., long-term integrity) of control is particularly important. This is affected by the potential for disruption by man; by the probability of occurrence of such natural phenomena as earthquakes, floods, windstorms, and glaciers; and by chemical and mechanical processes in the piles. Prediction of the long-term integrity of control methods becomes less certain as the period of concern increases. Beyond several thousand years, long-term geological processes and climatic change become the dominant factors.

Methods to prevent misuse by man and disruption by natural phenomena may be divided into those whose integrity depends upon man and his institutions ("active" controls) and those that do not ("passive" controls). Examples of active controls are fences, warning signs, restrictions on land use, and inspection and repair of semi-permanent tailings covers, temporary dikes, and drainage courses. Examples of passive controls are thick earthen covers, rock covers, massive earth and rock dikes, burial below grade, and moving piles out of locations highly subject to erosion, such as unstable river banks.

Erosion of tailings by wind, rain, and flooding can be inhibited by contouring the pile and its cover, by stabilizing the surface (with rock, for example) to make it resistant to erosion, and by constructing dikes. If necessary, erosion can be inhibited by burying tailings in a shallow pit or moving them away from a particularly flood-prone or otherwise geologically unstable site.

Earth covers can reduce the likelihood of human intrusion into the tailings, especially if the cover is thick enough. A one-meter earth cover provides only limited prevention of misuse since man commonly digs to such depths for many purposes. However, an earth cover in the range of 3 to 5 meters thickness will substantially reduce the likelihood of intrusion into tailings. The Agency is not aware of any historical examples of societies successfully maintaining active care of decentralized materials through public institutions for periods extending to many hundreds or thousands of years. We have concluded that primary reliance on passive measures (thick covers) is preferable since their long-term performance can be projected with more assurance than that of measures which rely on institutions and on continued expenditures for active maintenance.

An even better method for surface disposal of tailings is burial in surface pits with a 3 to 5 meter earth cover back up to the original grade (earth contour). The chance of misuse for this method is less than above surface disposal since the tailings disposal site would be indistinguishable from surrounding terrain. There would be no easily identifiable pile with rock covered slopes, clearly an indication of human activity.

Methods to control release of radon range from applying a simple barrier (such as an earthen cover) to such ambitious treatments as embedding tailings in cement or processing them to remove radium, the precursor of radon. Covering tailings with a permeable (porous) barrier, such as earth, delays radon diffusion so that most of it decays and is effectively retained in the cover. In addition to simple earthen covers, other less permeable materials such as asphalt, clay, or soil cement, usually in combination with earthen covers, may be used. The more permeable the covering material, the thicker it must be to achieve a given reduction in radon release. However, maintaining the integrity of very thin impermeable covers, such as plastic sheets, even over a period as short as several decades, is unlikely given the chemical and physical stresses present at piles.

The most likely constituents of cover for use to control tailings are locally available earthen materials. The effectiveness of an earthen cover as a barrier to radon depends most strongly on its moisture content. Typical clay soils in the uranium milling regions of the west exhibit ambient moisture contents of 9% to 12%. For non-clay soils, ambient moisture contents range from 6% to 10%. The following table provides, as an example, the cover thicknesses that would be required to reduce the flux of radon to 20 pCi/m^2s for the above ranges of soil moisture. Three examples of tailings are shown that cover the probable extreme values of radon flux from tailings at designated sites (100 to 1000 pCi/m^2s); the most common value is probably about 280 pCi/m^2s.

Estimated Cover Thickness in Meters to Reduce the Flux of Radon to 20 pCi/m^2s

Initial Tailings Flux (pCi/m^2s)	Percent Moisture Content of Cover			
	6	8	10	12
100	1.7	1.3	1.0	0.7
300	2.8	2.1	1.5	1.1
1000	4.1	3.2	2.4	1.8

Those values are for simple homogeneous covers. In practice, multi-layer covers using clay next to the tailings can be used to significantly reduce the total thickness required.

Methods that control radon emissions will also prevent transport of particulates from the tailings pile to air or to surface water. Similarly, permeable covers sufficiently thick for effective radon control will also absorb gamma radiation effectively (although thin impermeable covers will not).

Very effective long-term inhibition of misuse by man, as well as of releases to air and surface water, could be achieved by burying tailings in deep mined cavities. In this case, however, direct contact with ground water would be difficult to avoid. The potential hazards of tailings could also be reduced by chemically processing them to remove contaminants. Such processes have limited efficiencies, however, so the residual tailings would still require control. Furthermore, the extracted substances (e.g., radium and thorium) would be concentrated and would require further control.

We believe that groundwater protection after disposal of the tailings is provided by a well-designed and carefully maintained cap (cover). The requirements for closure (disposal) of surface impoundments for hazardous waste under the SWDA, as amended, include a cover designed and constructed to: (a) provide long-term minimization of the migration of liquids through the closed impoundment; (b) function with minimum maintenance; (c) promote drainage and minimize erosion or abrasion of the final cover; (d) accommodate settling and subsidence so that the cover's integrity is maintained; and (e) have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

EPA's view of the function of a liner contrasts somewhat with that of some members of the public and the regulated community. Some have argued that liners are devices that provide a perpetual seal against any migration from a waste management unit. EPA has concluded that the more reasonable assumption, based on what is known about the pressures placed on liners over time, is that any liner will begin to leak eventually. Others have argued that liners should be viewed as a means of retarding the movement of liquids from a unit for some period of time. While this view accords with how liners do in fact operate, EPA does not believe that this is a sound regulatory strategy for groundwater protection because it is principally designed to delay the appearance of groundwater contamination rather than to achieve a more permanent solution. Accordingly, EPA views liners as a barrier technology that can be best used to facilitate the removal of liquids from a waste management unit during its active life (including the closure period) and thereby provide a greater assurance of long-term protection at the facility.

While liners may remain effective at preventing migration from the unit until well after closure, their principal role occurs during the active life. After closure, EPA believes that a protective cap becomes the prime element of the liquids management strategy. A well-designed and carefully maintained cap can be quite effective at reducing the volume of liquids entering a unit and, therefore, can substantially reduce the potential for leachate generation at the unit for long periods.

The cost-effectiveness analysis of disposal methods presented in Chapter 4 concludes that the optimal level of control for both existing and new tailings piles is that reflected by a three-meter earth cover. As shown earlier in this chapter, this level of control is estimated to represent a radon release rate of about 20 pCi/m^2s. Therefore, our design standard for tailings disposal assumes this radon release limit. We feel that conformance with this radon release rate will prevent the misuse of the tailings by man, reduce radon emissions and gamma radiation exposure, and avoid the contamination of land and water for a long period of time.

6.2.3 Impacts of Proposed Standards

Environmental Impacts

Under the proposed standards, the tailings would remain covered and isolated for 1,000 years or more. Even under very severe conditions of erosion they would remain covered for at least 200 years. Radon emissions from disposed tailings would be well above normal levels for ordinary land, but well below levels if the tailings were not covered for thousands of years. Groundwater would be protected for thousands of years under the proposed standards.

The earthen cover material will be obtained from borrow pits close to the tailings pile. For tailings in surface mining locations, the incremental impact of a borrow pit, added to the impact of the surface mining, will be small to negligible. However, in locations where ore is taken from underground mines, the impact of a borrow pit can be significant. The area covered by a borrow pit could range from 16 ha (40 acres) up to 100 ha (250 acres) depending on the depth of the earth that can be removed. Thus, in some cases, the land surface disturbed to obtain cover material could be about the same as the area covered by tailings. In all cases, however, we assumed the topsoil at the borrow pit was saved, all high walls were graded to an 8:1 slope after the earthen cover material was removed, and the topsoil replaced and landscaped.

Health Impacts

The deaths avoided by control of radon are estimated for environmental emissions of radon only since we can make no reasonable estimate of the potential misuse of tailings. Under the proposed standards, the total deaths avoided (compared to tailings piles which are left uncontrolled) would be about 1400 for the first 100 years after disposal and many thousands during the first thousand years. These estimates relate to the cumulative generation of tailings through the year 2000 under baseline projection conditions. If no controls are implemented, the health risk to people living very near to tailings (600 meters from the center of the tailings pile) is about 4 chances in 100 of fatal lung cancer during their lifetime. This risk is reduced to about 2 chances in 1,000 under the proposed standards.

The misuse of tailings in constructing buildings poses the greatest hazard to human health associated with tailings. Under the proposed standard, we believe the possibility of unauthorized removal of the tailings will be unlikely for at least 1,000 years.

We estimate that covering the tailings under the proposed standard could result in 10 to 11 accidental deaths and 6 to 8 radiation induced deaths for all tailings (existing and new) to the year 2000. These deaths would occur among workers only.

Economic Impacts

The level of control required by the disposal standards approximates that which is provided by a three-meter earthen cover. Therefore, we have assumed that the cost of the economic impact cases in Chapter 5 which use this disposal method represent the cost of the proposed standards. We have determined that four cases - H_1, H_2, M_1, and M_2 - which use a three-meter cover are possible outcomes of meeting the requirements of the standards. These four cases provide a probable range in the estimated economic consequences of the standards.

All four of the impact cases assume disposal method ET3 - a three-meter earth cover above-grade with rock cover on the slopes - for existing tailings piles. Cases H_1 and M_1 assume disposal method NT4 for new mills which is identical to method ET3 for existing piles except that it requires the placement of a liner for groundwater protection during the operational phase of the mill. Cases H_2 and M_2 assume disposal method NT5 for new mills which calls for disposal below-grade with a three-meter earth cover and a liner. The major difference between these four cases pertains to the treatment of future tailings at existing mills. Cases H_1 and H_2 assume that future tailings are added to existing piles and then disposed in the same manner (ET3), while Cases M_1 and M_2 assume that existing mills will start new piles immediately for their future tailings and dispose of them in the same manner required for new mills (NT4 for M_1 and NT5 for M_2). The regulatory requirement which influences how future tailings at existing mills will be disposed (i.e., starting new piles or adding to existing piles) is the groundwater protection provision of the operations standard. This provision makes the SWDA groundwater protection standards applicable to uranium mill tailings. At this time, it is uncertain how the mills will comply with this requirement as it will most likely necessitate a site-by-site analysis by the regulatory agencies. We believe that the method of disposal of future tailings at existing mills will probably be somewhere between the extremes represented by these four impact cases.

Table 6.1 summarizes the cost and economic impacts of each of the four economic impact cases. Based on these estimates, we conclude that compliance with the proposed standards, assuming that other regulatory requirements did not exist, would cost the uranium milling industry from about 550 to 850 million dollars to dispose of all tailings which exist today at licensed sites and those which we estimate to be generated by the year 2000 under baseline projection conditions. These costs are present worth estimates (discounted at a 10 percent rate) expressed on a 1981 constant dollar basis. The range of industry disposal costs becomes 450 to 750 million dollars under low-growth projection conditions.

Table 6.1. Summary of Economic Impacts of Proposed Standards

Impact Characteristics	Economic Impact Cases H_1	 H_2	 M_1	 M_2
Disposal Method[(a)]				
Existing tailings	ET3	ET3	ET3	ET3
Future tailings, existing mills	ET3	ET3	NT4	NT5
Future tailings, new mills	NT4	NT5	NT4	NT5
Present Worth Cost (10^6 1981 dollars)				
Baseline Demand, 10% rate	530	549	793	834
Baseline Demand, 0% rate	1547	1627	2024	2146
Low Growth Demand, 10% rate	440	452	708	744
Low Growth Demand, 0% rate	1100	1149	1607	1701
Mill Closures[(b)]				
100% Cost Absorption, 20% Cash-flow margin	0	0	1	1
$1/lb Price Pass-Through, 20% Cash-flow margin	0	0	0	0
100% Cost Absorption, 25% Cash-flow margin	0	0	0	0
100% Cost Absorption, 15% Cash-flow margin	1	1	5	5
Uranium Price Increase (percents)[(c)]				
Model existing mill with lowest increase	2.4	2.4	7.6	8.0
Model new mill	6.6	7.1	6.6	7.1

(a) ET3 = Above-grade, 3m of earth, rock cover on slopes.
NT4 = Above-grade, 3m of earth, rock cover on slopes, liner.
NT5 = Below-grade, 3m of earth, liner.

(b) Expressed in small mill equivalents.

(c) Increases in production cost due to tailings disposal, assuming a base production cost of $30 per pound of U_3O_8.

We estimate that the average uranium price may increase from 2 to 8 percent. As explained in Chapter 5, this range in price increase is determined by the increases in production costs due to tailings disposal estimated for the least impacted model existing mill and the model new mill. In light of the currently poor economic condition of the industry and the threat of foreign competition, it is unlikely that mills will be able to pass through substantial portions of the disposal costs to their customers. Using our models, we estimate that if mills are forced to absorb the entire cost of disposal, one small mill may cease operation depending on the implementation of the groundwater protection requirements. If mills can add tailings to their existing piles indefinitely, we estimate that no mills will close (Cases H_1 and H_2). If mills are required to start new piles immediately for their future tailings, than one small model mill is estimated to close (Cases M_1 and M_2). We further estimate that under the conditions of a more favorable cash-flow or a limited price pass-through, this single mill closure would be avoided. On the other hand, with no pass-through and a lower cash-flow, two small model mills and a large model mill may close. (See Appendix A for the complete tabulation of the mill closure results for the various scenarios of price pass-through, cash flow, and industry demand.)

Based on one small model mill closure, we estimate a direct employment loss of about 70 mill employees and an indirect impact of an additional 85 jobs in the region. This total employment impact represents about 0.7 percent of the model region's work force. The total loss in payroll for the region is estimated to be about 3 million dollars or 1.1 percent of the area's payroll. These estimates assume that the mill closure is permanent, although it is possible that the mill may close temporarily and then reopen when market conditions improve.

We do not expect any macroeconomic impacts, including foreign trade, to take place as a result of the proposed standards.

These costs and economic impacts are not incremental costs of the proposed standards since much of this cost would probably occur in the absence of the standards due to other regulatory requirements. These other requirements are Nuclear Regulatory Commission (NRC) licensing regulations and State regulations. We did not estimate the costs imposed by these other regulations because that would require a site-specific investigation. Since our standards are required by Congress to be of general application, we decided to develop a generic analysis based on model facilities. Therefore, we could not estimate the net impact of the proposed standards.

REFERENCES FOR CHAPTER 6

FRC60 Federal Radiation Council, "Report No. 1, Background Material for the Development of Radiation Protection Standards," May 1960.

U.S.78 U.S. House of Representatives, "Report - Authorizing the Secretary of Energy to Enter into Cooperative Agreements with Certain States Respecting Radioactive Material at Existing Sites, Providing for the Regulation of Uranium Mill Tailings under the Atomic Energy Act of 1954, and for Other Purposes," 95th Congress, Report 95-1480, August 1978.

NRC80 U.S. Nuclear Regulatory Commission, *Final Generic Environmental Impact Statement on Uranium Milling*, NUREG-0706, September 1980.

APPENDIX A

MILL CLOSURE ANALYSIS

Appendix A

Mill Closure Analysis

A.1 Overview

This appendix presents the mill closure analysis. The purpose of the analysis is to assess the economic impact of the proposed standards on individual mills. Industry data on the number of mills in operation and the number and size of existing tailings piles as of January 1980 were used in this analysis. There were 21 mills operating at this time with tailings piles, plus piles existed at two other licensed mills which were no longer in operation.

The mill closure analysis is performed on a model mill basis. Since a preliminary investigation of production cost increases indicates that some mills may be significantly affected by tailings disposal costs under certain control requirements, we have performed an in-depth discounted cash flow analysis of several model mills. This analysis relates the control costs to the mill's cash flow to determine if the project is affordable. In this manner, we have assessed the likelihood of each model mill continuing operations while incurring various levels of tailings disposal costs.

A.2 Model Mills

The analysis is performed on a model mill basis. The model mills provide an indication of the degree of economic impact on all mills in the industry by incorporating the major characteristics of various segments of the industry. There are a large number of variables that can differ among actual mills. The models are not intended to provide an exact duplication of any actual or planned mill. The model mills differ according to capacity, remaining life, and size of existing tailings pile.

On the basis of capacity, the model existing mills are segmented into three categories, small, medium, and large, with capacities of 900, 1800, and 2700 metric tons of ore per day, respectively. New mills that may be built are represented by the medium size model mill.

Existing and new mills in the industry may vary considerably in their operating life. For example, some existing mills may be near the end of their operating life, while other existing mills have been operating for more than 20 years and may still have a long remaining operating life. For the model existing mills, the operating lives analyzed are limited to three choices in order to present a manageable number of models, but which are realistic; a model existing mill may have a remaining useful life of five, ten, or fifteen years. A model new mill is assumed to have a useful life of fifteen years. The significance of the remaining life of a mill is that a "short" remaining life permits less time to recover the costs of control than does a "long" remaining life. Also, the remaining life, together with the capacity of the mill and the capacity utilization rate, determines the amount of future tailings that will be generated by an existing mill.

Operating lives of five, ten, and fifteen years are chosen for several reasons. First, although some mills may have operating lives of less than five years or more than fifteen years, most existing mills should be within this range. Second, any existing mill with a remaining useful life of considerably less than five years is likely to experience a significant economic impact. Third, the difference between five years and fifteen years is sufficiently large to indicate differential control cost impacts based on remaining useful life. For economic reasons, a typical new mill is expected to have an operating life of approximately fifteen years, or longer (NRC80, EMJ79). Finally, it is difficult to determine precisely the life of a mill due to changing market conditions, the discovery of new ore deposits, changing technology, and so on. Therefore, five, ten, and fifteen year lives are believed to be reasonable.

The size of actual existing tailings piles varies considerably. Existing tailings piles are represented in the models by one of three tailings pile size categories: two million metric tons, seven million metric tons, or twenty million metric tons. A new model mill is projected to produce a tailings pile of 8.4 million metric tons over a fifteen year operating life.

Based on these differential model mill characteristics, there are 27 (3x3x3) possible model mills to be analyzed. After examining the characteristics of the 21 mills which were operating (as of January 1980) and had existing tailings piles, we placed each of them in one of 15 model mill categories. Table A.1 shows a generalized matrix of the three model mill variables (capacity, remaining life, tailings pile size) and the number of licensed mills that fit into each category. Tables A.2, A.3, and A.4 show the categorization of these mills according to capacity, tailings pile size, and remaining life.

Estimates of the remaining lives of mills had to be judgmentally determined since it is highly uncertain how long mills will continue to operate. These estimates, where possible, relied on information contained in Corporate Annual Reports, Securities and Exchange Commission 10-K Reports, or articles in trade journals. If estimates were not available from the above sources, the estimated ore reserves for a particular mine were divided by average production of its mill to yield an estimated remaining life. If neither of the above means was available, consideration was given to the start-up date for the mill.

Table A.1. Generalized Matrix of Existing Mills[a]

Mill Capacity (MT ore/day)	Remaining Life	Tailings Pile Size (10^6 MT)			Total Existing Mills By Capacity
		2	7	20	
900	5 years	1	1		
	10 years	1			
	15 years	1	3		7
1,800	5 years	1			
	10 years	2	1		
	15 years	1	3		8
2,700	5 years			1	
	10 years		1		
	15 years	1	1	2	6
	Total Existing Mills By Tailings Pile Size	8	10	3	21

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[a] As of January 1980. Excludes 2 licensed mills with 2 million MT tailings piles that were no longer operating (Edgemont, South Dakota, and Ray Point, Texas).

Source: Tables A.2, A.3, and A.4.

Table A.2. Existing Mills by Capacity[a]
(Metric Tons of Ore Per Day)

900 MT		1,800 MT		2,700 MT	
Size	Company	Size	Company	Size	Company
1,300	Cotter	1,500	Sohio-Reserve	3,600	UNC (Church Rock)
1,200	Union Carbide (Uravan)	2,200	Chevron	5,400	Anaconda
640	Rio Algom	1,800	Western Nuclear (Wellpinit)	6,300	Kerr-McGee
1,100	Atlas	2,000	Pathfinder (Gas Hills)	3,200	Homestake
400	Dawn	1,800	Rocky Mtn.	2,900	Conoco
900	Federal-American	1,500	Western Nuclear (Jeffrey City)	2,700	Exxon (Powder River)
1,200	Union Carbide (Gas Hills)	1,600	Pathfinder (Shirley Basin)		
		1,500	Petrotomics		
7 Mills		8 Mills		6 Mills	

[a] As of January 1980. Excludes mills at Edgemont, South Dakota, and Ray Point, Texas, that were no longer operating.

Source: Table 2.10.

Table A.3. Existing Mills by Tailings Pile Size[a]
(Millions of Metric Tons)

2		7		20	
Tailings Pile	Company	Tailings Pile	Company	Tailings Pile	Company
1.0	Cotter	8.8	Union Carbide (Uravan)	17.1	Anaconda
1.4	Sohio-Reserve	5.6	Conoco	24.6	Kerr-McGee
2.2	UNC (Church Rock)	7.8	Atlas	17.9	Homestake
1.2	Chevron	4.2	Federal-American		
1.6	Rio Algom	5.5	Pathfinder (Gas Hills)		
2.8	Dawn	8.0	Rocky Mtn. Energy		
1.3	Western Nuclear (Wellpinit)	5.7	Exxon (Powder River)		
2.0	Petrotomics	11.0	Western Nuclear (Jeffrey City)		
		7.6	Union Carbide (Gas Hills)		
		4.2	Pathfinder (Shirley Basin)		
8 Mills		10 Mills		3 Mills	

[a] As of January 1980. Excludes two licensed mills with 2 million MT tailings piles at Edgemont, South Dakota, and Ray Point, Texas, which were no longer operating.

Source: Table 2.10.

Table A.4. Existing Mills by Estimated Remaining Life[a]

5 Years	10 Years	15 Years
Union Carbide (Gas Hills)	Conoco	Cotter Corp.
Sohio-Reserve	Western Nuclear (Wellpinit)	UNC (Church Rock)
Anaconda	Dawn	Kerr-McGee
Chevron	Rocky Mountain Energy	Homestake
		Rio Algom
		Atlas
		Federal-American
		Pathfinder (Gas Hills)
		Exxon (Powder River)
		Western Nuclear (Jeffrey City)
		Union Carbide (Uravan)
		Pathfinder (Shirley Basin)
		Petrotomics

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[a] As of January 1980. Excludes licensed mills at Edgemont, South Dakota, and Ray Point, Texas, which were no longer operating.

A.3 Control Costs

The control costs for this analysis are the costs of disposing of the mill tailings. The detailed development of the model pile disposal costs has been explained in Appendix B of the EIS and will not be repeated here. There are three major categories of control costs. The first category is the cost to control existing tailings piles. The second category is the cost to control future tailings that an existing mill will generate during the remaining life of the operation. The third category is the cost to control tailings generated by a new mill. The cost to control an existing tailings pile is shown in Table A.5 for each economic impact case and model pile size.

Table A.6 shows for each impact case the unit cost and the total cost for a model existing mill to control future tailings. The cost to control future tailings is calculated by multiplying the cost of control per metric ton of tailings by the tons of tailings the model mill will generate during the remaining years of its assigned operating life. The future generation of tailings is a function of the mill's capacity and its capacity utilization rate (discussed in Section A.6).

Additional tailings that are generated by an existing mill can be controlled in one of two major ways, with different costs associated with each. First, future tailings can be added to existing piles, and therefore, both can be controlled in the same manner. This is assumed in impact cases C through H_4. Second, future tailings can be controlled in the same manner as tailings generated by a new mill and would require a new pile to be started. This is assumed in impact cases I through N.

The unit cost assumed for cases C through H_4 is the appropriate incremental cost of disposal of tailings which have been added to existing piles. These incremental unit costs have been estimated from the model existing pile disposal costs. The unit cost for Cases I through N is the average unit cost calculated from the model new pile disposal cost for the appropriate disposal method. The derivation of both of these types of unit costs is presented in Chapter 5.

Table A.7 shows the cost of control for the model new mill. The model new mill has a useful life of fifteen years and generates 8.4 million metric tons of tails.

Tables A.8a, A.8b, and A.8c show the combined control costs to control an existing tailings pile at a model mill, plus the control costs for future tailings generated during the remaining life of the operation. In actuality, no small or medium-sized mills have a tailings pile in the 20 million metric ton category. Therefore, no control costs are shown for a 20 million metric ton tailings pile at a small or medium-sized model mill.

Table A.5. Control Costs for Model Existing Tailings PIles (Millions of 1981 Dollars)

Economic Impact Case	Tailings Pile Size		
	2 (10^6 MT)	7 (10^6 MT)	20 (10^6 MT)
A	-	-	-
B_1	-	-	-
B_2	-	-	-
B_3	-	-	-
C	3.9	5.7	11.1
D	3.9	5.7	11.1
E	3.8	7.0	14.4
F	3.8	7.0	14.4
G	12.8	17.4	32.5
H_1	6.9	11.4	22.3
H_2	6.9	11.4	22.3
H_3	7.6	13.9	29.2
H_4	11.9	19.9	40.6
I	-	-	-
J	3.9	5.7	11.1
K	3.8	7.0	14.4
L	12.8	17.4	32.5
M_1	6.9	11.4	22.3
M_2	6.9	11.4	22.3
M_3	7.6	13.9	29.2
M_4	11.9	19.9	40.6
N	12.3	43.7	126.9

Table A.6. Cost to Control Future Tailings at Existing Mills (Millions of 1981 Dollars)

Economic Impact Case	Unit Cost of Disposal ($/MT Tailings)	900 MT ore/day			1,800 MT ore/day			2,700 MT ore/day		
		1.2[a] 5 Yrs	2.7[a] 10 Yrs	4.1[a] 15 Yrs	2.4[a] 5 Yrs	5.3[a] 10 Yrs	8.2[a] 15 Yrs	3.6[a] 5 Yrs	6.0[a] 10 Yrs	12.4[a] 15 Yrs
A	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_1	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_2	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_3	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	0.39	0.5	1.0	1.6	0.9	2.1	3.2	1.4	3.1	4.8
D	0.39	0.5	1.0	1.6	0.9	2.1	3.2	1.4	3.1	4.8
E	0.60	0.7	1.6	2.5	1.5	3.2	5.0	2.2	4.8	7.5
F	0.60	0.7	1.6	2.5	1.5	3.2	5.0	2.2	4.8	7.5
G	1.04	1.3	2.8	4.3	2.5	5.6	8.6	3.8	8.3	12.9
H_1	0.87	1.0	2.3	3.6	2.1	4.6	7.2	3.1	7.0	10.8
H_2	0.87	1.0	2.3	3.6	2.1	4.6	7.2	3.1	7.0	10.8
H_3	1.22	1.5	3.3	5.0	2.9	6.5	10.1	4.4	9.8	15.1
H_4	1.60	1.9	4.3	6.6	3.8	8.5	13.2	5.8	12.8	19.8
I	4.26	5.1	11.4	17.6	10.3	22.8	35.2	15.4	34.2	52.7
J	4.26	5.1	11.4	17.6	10.3	22.8	35.2	15.4	34.2	52.7
K	3.99	4.8	10.7	16.5	9.6	21.3	32.9	14.4	32.0	49.4
L	4.26	5.1	11.4	17.6	10.3	22.8	35.2	15.4	34.2	52.7
M_1	3.99	4.8	10.7	16.5	9.6	21.3	32.9	14.4	32.0	49.4
M_2	4.26	5.1	11.4	17.6	10.3	22.8	35.2	15.4	34.2	52.7
M_3	4.26	5.1	11.4	17.6	10.3	22.8	35.2	15.4	34.2	52.7
M_4	5.23	6.3	14.0	21.6	12.6	27.9	43.1	18.9	41.9	64.7
N	4.26	5.1	11.4	17.6	10.3	22.8	35.2	15.4	34.2	52.7

[a] Future production of uranium (million MT of ore).

Table A.7. Control Costs for a Model New Tailings Pile (Millions of 1981 Dollars)

Regulatory Option	Tailings Pile Size 8.4 (x 10^6 MT)
A	1.2
B_1	27.4
B_2	35.8
B_3	91.2
C	25.8
D	35.8
E	27.4
F	33.5
G	35.8
H_1	33.5
H_2	35.8
H_3	35.8
H_4	43.9
I	35.8
J	35.8
K	33.5
L	35.8
M_1	33.5
M_2	35.8
M_3	35.8
M_4	43.9
N	35.8

Table A.8a. Total Disposal Cost for Small Model Existing Mill (Existing Tails Plus New Tails, Millions of 1981 Dollars)

Economic Impact Case	900 MT ore/day					
	2(a)			7(a)		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
A	0.0	0.0	0.0	0.0	0.0	0.0
B_1	0.0	0.0	0.0	0.0	0.0	0.0
B_2	0.0	0.0	0.0	0.0	0.0	0.0
B_3	0.0	0.0	0.0	0.0	0.0	0.0
C	4.4	4.9	5.5	6.2	6.7	7.3
D	4.4	4.9	5.5	6.2	6.7	7.3
E	4.5	5.4	6.3	7.7	8.6	9.5
F	4.5	5.4	6.3	7.7	8.6	9.5
G	14.1	15.6	17.1	18.7	20.2	21.7
H_1	7.9	9.2	10.5	12.4	13.7	15.0
H_2	7.9	9.2	10.5	12.4	13.7	15.0
H_3	9.1	10.9	12.6	15.4	17.2	18.9
H_4	13.8	16.2	18.5	21.8	24.2	26.5
I	5.1	11.4	17.6	5.1	11.4	17.6
J	9.0	15.3	21.5	10.8	17.1	23.3
K	8.6	14.5	20.3	11.8	17.7	23.5
L	17.9	24.2	30.4	22.5	28.8	35.0
M_1	11.7	17.6	23.4	16.2	22.1	27.9
M_2	12.0	18.3	24.5	16.5	22.8	29.0
M_3	12.7	19.0	25.2	19.0	25.3	31.5
M_4	18.2	25.9	33.5	26.2	33.9	41.5
N	17.5	23.8	30.0	48.8	55.1	61.3

(a)Size of existing tailings pile, million MT.

Table A.8b. Total Disposal Cost for a Medium Model Existing Mill (Existing Tails Plus New Tails, Millions of 1981 Dollars)

Economic Impact Case	1,800 MT ore/day					
	2(a)			7(a)		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
A	0.0	0.0	0.0	0.0	0.0	0.0
B_1	0.0	0.0	0.0	0.0	0.0	0.0
B_2	0.0	0.0	0.0	0.0	0.0	0.0
B_3	0.0	0.0	0.0	0.0	0.0	0.0
C	4.8	6.0	7.1	6.6	7.8	8.9
D	4.8	6.0	7.1	6.6	7.8	8.9
E	5.3	7.0	8.8	8.5	10.2	12.0
F	5.3	7.0	8.8	8.5	10.2	12.0
G	15.3	18.4	21.4	19.9	23.0	26.0
H_1	9.0	11.5	14.1	13.5	16.0	18.6
H_2	9.0	11.5	14.1	13.5	16.0	18.6
H_3	10.5	14.1	17.7	16.8	20.4	24.0
H_4	15.7	20.4	25.1	23.7	28.4	33.1
I	10.3	22.8	35.2	10.3	22.8	35.2
J	14.2	26.7	39.1	16.0	28.5	40.9
K	13.4	25.1	36.7	16.6	28.3	39.9
L	23.1	35.6	48.0	27.7	40.2	52.6
M_1	16.5	28.2	39.8	21.0	32.7	44.3
M_2	17.2	29.7	42.1	21.7	34.2	46.6
M_3	17.9	30.4	42.8	24.2	36.7	49.1
M_4	24.5	39.8	55.0	32.5	47.8	63.0
N	22.7	35.2	47.6	54.0	66.5	78.9

(a) Size of existing tailings pile, million MT.

Table A.8c. Total Disposal Cost for a Large Model Existing Mill (Existing Tails Plus New Tails, Millions of 1981 Dollars)

Economic Impact Case	2,700 MT ore/day								
	2(a)			7(a)			20(a)		
	5 Yrs	10 Yrs	15 Yrs	5 Yrs	10 Yrs	15 Yrs	5 Yrs	10 Yrs	15 Yrs
A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	5.3	7.0	8.7	7.1	8.8	10.5	12.5	14.2	15.9
D	5.3	7.0	8.7	7.1	8.8	10.5	12.5	14.2	15.9
E	6.0	8.6	11.3	9.2	11.8	14.5	16.6	19.2	21.9
F	6.0	8.6	11.3	9.2	11.8	14.5	16.6	19.2	21.9
G	16.6	21.1	25.7	21.2	25.7	30.3	36.3	40.8	45.4
H_1	10.0	13.9	17.7	14.5	18.4	22.2	25.4	29.3	33.1
H_2	10.0	13.9	17.7	14.5	18.4	22.2	25.4	29.3	33.1
H_3	12.0	17.4	22.7	18.3	23.7	29.0	33.6	39.0	44.3
H_4	17.7	24.7	31.7	25.7	32.7	39.7	46.4	53.4	60.4
I	15.4	34.2	52.7	15.4	34.2	52.7	15.4	34.2	52.7
J	19.3	38.1	56.6	21.1	39.9	58.4	26.5	45.3	63.8
K	18.2	35.8	53.2	21.4	39.0	56.4	28.8	46.4	63.8
L	28.2	47.0	65.5	32.8	51.6	70.1	47.9	66.7	85.2
M_1	21.3	38.9	56.3	25.8	43.4	60.8	36.7	54.3	71.7
M_2	22.3	41.1	59.6	26.8	45.6	64.1	37.7	56.5	75.0
M_3	23.0	41.8	60.3	29.3	48.1	66.6	44.6	63.4	81.9
M_4	30.8	53.8	76.6	38.8	61.8	84.6	59.5	82.5	105.3
N	27.8	46.6	65.1	59.1	77.9	96.4	142.6	161.4	179.9

(a) Size of existing tailings pile, million MT.

A.4 Production Cost Increases

One way to gain a perspective on the degree of impact that the control costs may have on the model mills is to calculate the percentage change in production costs due to tailings disposal. This relatively simple estimation will provide an indication of both how significant the costs are and how the impacts vary by model mill. Table A.9a shows the control cost increase for the small existing mill expressed as dollars per metric ton of ore milled (assuming a remaining life of 5 years, 10 years, or 15 years). This unit control cost is derived by dividing the total costs shown on Table A.8a by the approximate number of metric tons of future production as shown on Table A.9a. Table A.9b expresses this cost increase in terms of dollars per pound of U_3O_8 produced. Assuming an average ore grade of .1 percent and a recovery rate of 93 percent, one metric ton of ore yields about two pounds of U_3O_8. Therefore, the cost per metric ton of ore divided by two equals the cost per pound of U_3O_8. Finally, Table A.9c shows the percentage increase in production cost assuming a base production cost of $30 per pound of U_3O_8. For the lack of company-specific cost data, we have assumed that the $30 per pound production cost applies uniformly to all mills. Tables A.10 (a,b,c) and A.11 (a,b,c) present the same type of information for the medium and large existing mills. Table A.12 presents the same information for the model new mill.

Upon examining the estimated production cost increases, it is evident that for some economic impact cases the increases are substantial. Also, some of the model mills are affected significantly more than others. Because the control costs may be significant, we conclude that a plant closure analysis is necessary to determine the economic impact on the mills since it is unlikely that they can pass-through a large part of the control cost to their customers.

A.5 Discounted Cash Flow Analysis

The impact of the control costs on the model mills can be assessed using the discounted cash flow (DCF) technique. DCF is a financial analysis technique that indicates if a project is justified on economic grounds. Among financial analysis techniques, DCF is the most comprehensive due to two principal advantages over most other financial analysis techniques. First, DCF considers the time value of money. Second, DCF considers the cash flow items that are applicable to a project, rather than just the earnings applicable to a project. Other than earnings, the principal cash flow items are depreciation and depletion. Although depreciation and depletion are legal business expenses for income tax purposes, they do not represent actual cash expenses for the firm for the year. Therefore, in order to calculate cash flows, depreciation and depletion are added to earnings.

Table A.9a. Production Cost Increases for a Small Model Existing Mill, $/Metric Ton of Ore

Economic Impact Case	2(a)			7(a)		
	1.2(b) 5 Years	2.7(b) 10 Years	4.1(b) 15 Years	1.2(b) 5 Years	2.7(b) 10 Years	4.1(b) 15 Years
A	0.00	0.00	0.00	0.00	0.00	0.00
B_1	0.00	0.00	0.00	0.00	0.00	0.00
B_2	0.00	0.00	0.00	0.00	0.00	0.00
B_3	0.00	0.00	0.00	0.00	0.00	0.00
C	3.63	1.85	1.33	5.12	2.52	1.77
D	3.63	1.85	1.33	5.12	2.52	1.77
E	3.76	2.03	1.53	6.42	3.22	2.30
F	3.76	2.03	1.53	6.42	3.22	2.30
G	11.67	5.83	4.14	15.49	7.55	5.26
H_1	6.60	3.45	2.54	10.33	5.13	3.63
H_2	6.60	3.45	2.54	10.33	5.13	3.63
H_3	7.53	4.06	3.06	12.76	6.42	4.59
H_4	11.48	6.05	4.48	18.12	9.04	6.42
I	4.26	4.26	4.26	4.26	4.26	4.26
J	7.50	5.72	5.21	8.99	6.39	5.64
K	7.14	5.41	4.91	9.80	6.61	5.69
L	14.89	9.05	7.36	18.71	10.77	8.48
M_1	9.72	6.57	5.66	13.45	8.25	6.75
M_2	9.99	6.84	5.93	13.73	8.53	7.03
M_3	10.57	7.11	6.10	15.80	9.46	7.63
M_4	15.11	9.68	8.11	21.75	12.67	10.05
N	14.56	8.90	7.27	40.54	20.61	14.86

(a) Size of existing tailings pile, million MT.

(b) Future production of uranium (million MT of ore).

Table A.9b. Production Cost Increases for a Small Model Existing Mill, \$/Pound of U_3O_8

Economic Impact Case	$2^{(a)}$			$7^{(a)}$		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
A	0.00	0.00	0.00	0.00	0.00	0.00
B_1	0.00	0.00	0.00	0.00	0.00	0.00
B_2	0.00	0.00	0.00	0.00	0.00	0.00
B_3	0.00	0.00	0.00	0.00	0.00	0.00
C	1.81	0.92	0.67	2.56	1.26	0.88
D	1.81	0.92	0.67	2.56	1.26	0.88
E	1.88	1.01	0.76	3.21	1.61	1.15
F	1.88	1.01	0.76	3.21	1.61	1.15
G	5.83	2.91	2.07	7.74	3.78	2.63
H_1	3.30	1.73	1.27	5.17	2.57	1.82
H_2	3.30	1.73	1.27	5.17	2.57	1.82
H_3	3.76	2.03	1.53	6.38	3.21	2.29
H_4	5.74	3.02	2.24	9.06	4.52	3.21
I	2.13	2.13	2.13	2.13	2.13	2.13
J	3.75	2.86	2.60	4.50	3.20	2.82
K	3.57	2.70	2.45	4.90	3.30	2.84
L	7.44	4.53	3.68	9.35	5.39	4.24
M_1	4.86	3.28	2.83	6.73	4.13	3.38
M_2	5.00	3.42	2.97	6.86	4.26	3.51
M_3	5.29	3.55	3.05	7.90	4.73	3.82
M_4	7.55	4.84	4.06	10.87	6.34	5.03
N	7.28	4.45	3.63	20.27	10.31	7.4

(a) Size of existing tailings pile, million MT.

Table A.9c. Production Cost Increases for a Small Model Existing Mill, Percentage Increase(a)

Economic Impact Case	2(b)			7(b)		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
A	0.0	0.0	0.0	0.0	0.0	0.0
B_1	0.0	0.0	0.0	0.0	0.0	0.0
B_2	0.0	0.0	0.0	0.0	0.0	0.0
B_3	0.0	0.0	0.0	0.0	0.0	0.0
C	6.0	3.1	2.2	8.5	4.2	2.9
D	6.0	3.1	2.2	8.5	4.2	2.9
E	6.3	3.4	2.5	10.7	5.4	3.8
F	6.3	3.4	2.5	10.7	5.4	3.8
G	19.4	9.7	6.9	25.8	12.6	8.8
H_1	11.0	5.8	4.2	17.2	8.6	6.1
H_2	11.0	5.8	4.2	17.2	8.6	6.1
H_3	12.5	6.8	5.1	21.3	10.7	7.6
H_4	19.1	10.1	7.5	30.2	15.1	10.7
I	7.1	7.1	7.1	7.1	7.1	7.1
J	12.5	9.5	8.7	15.0	10.7	9.4
K	11.9	9.0	8.2	16.3	11.0	9.5
L	24.8	15.1	12.3	31.2	18.0	14.1
M_1	16.2	10.9	9.4	22.4	13.8	11.3
M_2	16.7	11.4	9.9	22.9	14.2	11.7
M_3	17.6	11.8	10.2	26.3	15.8	12.7
M_4	25.2	16.1	13.5	36.2	21.1	16.8
N	24.3	14.8	12.1	67.6	34.4	24.8

(a) Assumes a base production cost of $30 per pound of U_3O_8.

(b) Size of existing tailings pile, million MT.

Table A.10a. Production Cost Increases for a Medium Model Existing Mill, $/Metric Ton of Ore

Economic Impact Case	2(a)			7(a)		
	2.4(b) 5 Years	5.3(b) 10 Years	8.2(b) 15 Years	2.4(b) 5 Years	5.3(b) 10 Years	8.2(b) 15 Years
A	0.00	0.00	0.00	0.00	0.00	0.00
B_1	0.00	0.00	0.00	0.00	0.00	0.00
B_2	0.00	0.00	0.00	0.00	0.00	0.00
B_3	0.00	0.00	0.00	0.00	0.00	0.00
C	2.01	1.12	0.86	2.75	1.45	1.08
D	2.01	1.12	0.86	2.75	1.45	1.08
E	2.18	1.32	1.07	3.51	1.91	1.45
F	2.18	1.32	1.07	3.51	1.91	1.45
G	6.35	3.44	2.59	8.26	4.30	3.15
H_1	3.73	2.16	1.71	5.60	3.00	2.25
H_2	3.73	2.16	1.71	5.60	3.00	2.25
H_3	4.37	2.64	2.14	6.99	3.82	2.90
H_4	6.54	3.82	3.04	9.86	5.32	4.01
I	4.26	4.26	4.26	4.26	4.26	4.26
J	5.88	4.99	4.73	6.63	5.33	4.95
K	5.57	4.70	4.45	6.69	5.30	4.84
L	9.58	6.66	5.81	11.48	7.52	6.37
M_1	6.85	5.28	4.82	8.72	6.12	5.37
M_2	7.13	5.55	5.10	8.99	6.39	5.64
M_3	7.42	5.68	5.18	10.03	6.86	5.95
M_4	10.17	7.45	6.67	13.49	8.95	7.64
N	9.41	6.58	5.76	22.40	12.44	9.56

(a) Size of existing tailings pile, million MT.

(b) Future production of uranium (million MT of ore).

Table A.10b. Production Cost Increases for a Medium Model Existing Mill $/Pound of U_3O_8

Economic Impact Case	2(a)			7(a)		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
A	0.00	0.00	0.00	0.00	0.00	0.00
B_1	0.00	0.00	0.00	0.00	0.00	0.00
B_2	0.00	0.00	0.00	0.00	0.00	0.00
B_3	0.00	0.00	0.00	0.00	0.00	0.00
C	1.00	0.56	0.43	1.38	0.73	0.54
D	1.00	0.56	0.43	1.38	0.73	0.54
E	1.09	0.66	0.53	1.76	0.96	0.73
F	1.09	0.66	0.53	1.76	0.96	0.73
G	3.18	1.72	1.30	4.13	2.15	1.57
H_1	1.87	1.08	0.85	2.80	1.50	1.13
H_2	1.87	1.08	0.85	2.80	1.50	1.13
H_3	2.19	1.32	1.07	3.49	1.91	1.45
H_4	3.27	1.91	1.52	4.93	2.66	2.00
I	2.13	2.13	2.13	2.13	2.13	2.13
J	2.94	2.50	2.37	3.31	2.66	2.48
K	2.78	2.35	2.22	3.45	2.65	2.42
L	4.79	3.33	2.91	5.74	3.76	3.19
M_1	3.43	2.64	2.41	4.36	3.06	2.68
M_2	3.56	2.78	2.55	4.50	3.20	2.82
M_3	3.71	2.84	2.59	5.02	3.43	2.97
M_4	5.08	3.73	3.33	6.74	4.47	3.82
N	4.70	3.29	2.88	11.20	6.22	4.78

(a) Size of existing tailings pile, million MT.

Table A.10c. Production Cost Increases for a Medium Model Existing Mill, Percentage Increase(a)

Economic Impact Case	2(b)			7(b)		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
A	0.0	0.0	0.0	0.0	0.0	0.0
B_1	0.0	0.0	0.0	0.0	0.0	0.0
B_2	0.0	0.0	0.0	0.0	0.0	0.0
B_3	0.0	0.0	0.0	0.0	0.0	0.0
C	3.3	1.9	1.4	4.6	2.4	1.8
D	3.3	1.9	1.4	4.6	2.4	1.8
E	3.6	2.2	1.8	5.9	3.2	2.4
F	3.6	2.2	1.8	5.9	3.2	2.4
G	10.6	5.7	4.3	13.8	7.2	5.2
H_1	6.2	3.6	2.8	9.3	5.0	3.8
H_2	6.2	3.6	2.8	9.3	5.0	3.8
H_3	7.3	4.4	3.6	11.6	6.4	4.8
H_4	10.9	6.4	5.1	16.4	8.9	6.7
I	7.1	7.1	7.1	7.1	7.1	7.1
J	9.8	8.3	7.9	11.0	8.9	8.3
K	9.3	7.8	7.4	11.5	8.8	8.1
L	16.0	11.1	9.7	19.1	12.5	10.6
M_1	11.4	8.8	8.0	14.5	10.2	8.9
M_2	11.9	9.3	8.5	15.0	10.7	9.4
M_3	12.4	9.5	8.6	16.7	11.4	9.9
M_4	16.9	12.4	11.1	22.5	14.9	12.7
N	15.7	11.0	9.6	37.3	20.7	15.9

(a) Assumes a base production cost of \$30 per pound of U_3O_8.

(b) Size of existing tailings pile, million MT.

Table A.11a. Production Cost Increases for a Large Model Existing Mill, $/Metric Ton of Ore

Economic Impact Case	2(a)			7(a)			20(a)		
	3.6(b) 5 Years	8.0(b) 10 Years	12.4(b) 15 Years	3.6(b) 5 Years	8.0(b) 10 Years	12.4(b) 15 Years	3.6(b) 5 Years	8.0(b) 10 Years	12.4(b) 15 Years
A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C	1.47	0.87	0.70	0.00	0.00	0.00	0.00	0.00	0.00
D	1.47	0.87	0.70	1.97	1.10	0.85	3.46	1.77	1.28
E	1.66	1.08	0.91	1.97	1.10	0.85	3.46	1.77	1.28
F	1.66	1.08	0.91	2.54	1.48	1.17	4.59	2.40	1.77
G	4.58	2.64	2.08	2.54	1.48	1.17	4.59	2.40	1.77
H_1	2.78	1.73	1.43	5.86	3.21	2.45	10.03	5.09	3.67
H_2	2.78	1.73	1.43	4.02	2.29	1.79	7.04	3.65	2.67
H_3	3.32	2.17	1.83	4.02	2.29	1.79	7.04	3.65	2.67
H_4	4.89	3.08	2.56	5.07	2.95	2.34	9.30	4.86	3.58
I	4.26	4.26	4.26	7.10	4.08	3.20	12.83	6.66	4.88
J	5.34	4.75	4.58	4.26	4.26	4.26	4.26	4.26	4.26
K	5.04	4.46	4.30	5.84	4.97	4.72	7.33	5.65	5.16
L	7.80	5.86	5.30	5.93	4.86	4.55	7.97	5.78	5.15
M_1	5.90	4.85	4.55	9.08	6.43	5.67	13.26	8.31	6.89
M_2	6.17	5.12	4.82	7.14	5.41	4.91	10.16	6.77	5.79
M_3	6.37	5.21	4.88	7.42	5.68	5.18	10.43	7.04	6.06
M_4	8.52	6.71	6.19	8.11	6.00	5.39	12.34	7.90	6.62
N	7.69	5.81	5.26	10.73	7.71	6.83	16.46	10.29	8.51
				16.36	9.71	7.79	39.46	20.12	14.54

(a) Size of existing tailings pile, million MT.

(b) Future production of uranium (million MT of ore).

Table A.11b. Production Cost Increases for a Large Model Existing Mill, \$/Pound of U_3O_8

Economic Impact Case	2(a)			7(a)			20(a)		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C	0.73	0.44	0.35	0.98	0.55	0.42	1.73	0.89	0.64
D	0.73	0.44	0.35	0.98	0.55	0.42	1.73	0.89	0.64
E	0.83	0.54	0.46	1.27	0.74	0.59	2.29	1.20	0.88
F	0.83	0.54	0.46	1.27	0.74	0.59	2.29	1.20	0.88
G	2.29	1.32	1.04	2.93	1.61	1.22	5.02	2.55	1.83
H_1	1.39	0.86	0.71	2.01	1.15	0.90	3.52	1.83	1.34
H_2	1.39	0.86	0.71	2.01	1.15	0.90	3.52	1.83	1.34
H_3	1.66	1.08	0.92	2.53	1.48	1.17	4.65	2.43	1.79
H_4	2.44	1.54	1.28	3.55	2.04	1.60	6.42	3.33	2.44
I	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13
J	2.67	2.37	2.29	2.92	2.49	2.36	3.67	2.82	2.58
K	2.52	2.23	2.15	2.96	2.43	2.28	3.99	2.89	2.58
L	3.90	2.93	2.65	4.54	3.22	2.83	6.63	4.16	3.44
M_1	2.95	2.42	2.27	3.57	2.70	2.45	5.08	3.38	2.90
M_2	3.09	2.56	2.41	3.71	2.84	2.59	5.22	3.52	3.03
M_3	3.18	2.60	2.44	4.05	4.00	2.69	6.17	3.95	3.31
M_4	4.26	3.36	3.09	5.37	3.85	3.42	8.23	5.14	4.25
N	3.85	2.90	2.63	8.18	4.86	3.90	19.73	10.06	7.27

(a) Size of existing tailings pile, million MT.

Table A.11c. Production Cost Increases for a Large Model Existing Mill, Percentage Increase[a]

Economic Impact Case	2[b]			7[b]			20[b]		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	2.4	1.5	1.2	3.3	1.8	1.4	5.8	3.0	2.1
D	2.4	1.5	1.2	3.3	1.8	1.4	5.8	3.0	2.1
E	2.8	1.8	1.5	4.2	2.5	2.0	7.6	4.0	2.9
F	2.8	1.8	1.5	4.2	2.5	2.0	7.6	4.0	2.9
G	7.6	4.4	3.5	9.8	5.4	4.1	16.7	8.5	6.1
H_1	4.6	2.9	2.4	6.7	3.8	3.0	11.7	6.1	4.5
H_2	4.6	2.9	2.4	6.7	3.8	3.0	11.7	6.1	4.5
H_3	5.5	3.6	3.1	8.4	4.9	3.9	15.5	8.1	6.0
H_4	8.1	5.1	4.3	11.8	6.8	5.3	21.4	11.1	8.1
I	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
J	8.9	7.9	7.6	9.7	8.3	7.9	12.2	9.4	8.6
K	8.4	7.4	7.2	9.9	8.1	7.6	13.3	9.6	8.6
L	13.0	9.8	8.8	15.1	10.7	9.4	22.1	13.9	11.5
M_1	9.8	8.1	7.6	11.9	9.0	8.2	16.9	11.3	9.7
M_2	10.3	8.5	8.0	12.4	9.5	8.6	17.4	11.7	10.1
M_3	10.6	8.7	8.1	13.5	10.0	9.0	20.6	13.2	11.0
M_4	14.2	11.2	10.3	17.9	12.8	11.4	27.4	17.1	14.2
N	12.8	9.7	8.8	27.3	16.2	13.0	65.8	33.5	24.2

[a] Assumes a base production cost of $30 per pound of U_3O_8.

[b] Size of existing tailings pile, million MT.

Table A.12. Production Cost Increases for a Model New Mill

Economic Impact Case	$/Metric Ton of Ore	$/Pound of U_3O_8	Percentage Increase in Production Cost[(a)]
A	0.14	0.07	0.2
B_1	3.26	1.63	5.4
B_2	4.26	2.13	7.1
B_3	10.86	5.43	18.1
C	3.07	1.54	5.1
D	4.26	2.13	7.1
E	3.26	1.63	5.4
F	3.99	1.99	6.6
G	4.26	2.13	7.1
H_1	3.99	1.99	6.6
H_2	4.26	2.13	7.1
H_3	4.26	2.13	7.1
H_4	5.23	2.61	8.7
I	4.26	2.13	7.1
J	4.26	2.13	7.1
K	3.99	1.99	6.6
L	4.26	2.13	7.1
M_1	3.99	1.99	6.6
M_2	4.26	2.13	7.1
M_3	4.26	2.13	7.1
M_4	5.23	2.61	8.7
N	4.26	2.13	7.1

(a) Assumes a base production cost of $30 per pound of U_3O_8.

DCF is most useful in complex analytical situations, such as when earnings or cash flows are fluctuating significantly, or when several pollution control investments for a single project must be made during different time periods, or when control costs are very high. In situations that involve few variables, or variables that only change slightly, a technique less comprehensive and time-consuming than DCF, such as Return on Investment (ROI), may be sufficient.

The data for the DCF analysis should be as specific as possible to the relevant profit center. This may be difficult in some cases because individual plant data may not be publicly available from multi-plant companies involved in several business segments. Also, in some circumstances, factors that cannot readily be quantified and identified in a DCF analysis may be important. For example, some industries may involve several stages of production, each of which is a separate profit center but which may all be closely related within a single company, such as mining, smelting, and refining. Another possibility is that several products may complement each other and, hence, may be collectively important in order to allow a firm to offer a complete product line to its customers.

The complexity of a DCF analysis and its parameters can be adjusted depending on the data available and the overall rigor necessary for any particular case. The parameters for each year for a typical DCF analysis are presented below in Table A.13. Most of the parameters shown in Table A.13 are self-explanatory. As particular circumstances warrant, the costs parameter can represent total costs, or the costs parameter can be separated into fixed costs and variable costs or separated into more detailed costs such as energy, labor, materials, and so on. Depreciation can be presented using the straight-line method or an accelerated method. Depreciation is typically presented using the straight-line method because it is the easiest method to calculate, and it yields more conservative results than accelerated methods. Depletion is a variable that applies only to extractive types of investments, such as mining and drilling for oil. State taxes is an example of a parameter not shown in Table A.13, but which may be necessary in particular analyses. Some analyses may require a provision for a tax loss carryforward. Normally, investments are financed partially with debt and partially with equity; however, if a particular investment is financed totally with equity, then the interest and principal repayment parameters, which are due to debt, will not be present. The sustaining capital expenditures variable represents expenditures required to maintain the plant in good working condition and maintain salvage value. Rather than include sustaining capital expenditures in an analysis, an alternative assumption that is sometimes used is that salvage value declines to zero due to a lack of sustaining capital expenditures. The conventional practice with respect to the discount rate is to use a discount rate that assumes cash flows occur at a single (discrete) point in time at the end of each year, rather than a discount rate that assumes cash flows occur continuously throughout a year. The variables that are affected by inflation, such as revenue and costs, can be expressed in either real or nominal terms, but the choice must be consistent throughout an analysis for all relevant variables.

Table A.13. Discounted Cash Flow Parameters

1. Revenue
2. Costs
3. Depreciation
4. Interest
5. Control O&M Cost
6. Control Depreciation
7. Control Interest
8. Earnings Before Tax [1 - (2, 3, 4, 5, 6, 7)]
9. Depletion
10. Tax Liability
11. Investment Tax Credit
12. Control Investment Tax Credit
13. Minimum Tax
14. Total Tax Due [(10 - (11 + 12))+ 13]
15. Earnings After Tax [8 - 14]
16. Depreciation
17. Control Depreciation
18. Depletion
19. Cash Flow Before Deduction [15 + 16 + 17 + 18]
20. Principal Payments
21. Control Principal Payments
22. Sustaining Capital Expenditures
23. Net Cash Flow [19 - (20 + 21 + 22)]
24. Discount Factor
25. Discounted Net Cash Flow [23 x 24]

Each annual net cash flow is calculated and then discounted. The discounted net cash flows for all years of a project life are then summed to yield the present value of the cash flows. The initial investment is subtracted from the present value of the cash flows to yield the net present value (NPV). The complete process using simple assumptions for ease of presentation is shown in Table A.14. Several items that are not shown in Table A.14 that may be present in some analyses are salvage value, the recovery of working capital at the end of a project's life, and terminal value. Terminal value is a means of representing any continuing value of a project beyond the years shown in a detailed DCF analysis. For example, Table A.14 presents a ten-year analysis period. If the project illustrated in Table A.14 is expected to continue in operation beyond ten years, terminal value could be used to represent the continuing life of the project.

If the NPV of a project is positive, this means that the project returns more than the firm's cost of capital and the project should be accepted. If the NPV of a project is negative, this means that a project returns less than the firm's cost of capital and the project should be rejected. If the NPV of a project is zero, this means that the project returns exactly the firm's cost of capital and the project should be accepted. However, as a practical matter, there is an element of uncertainty associated with most data and projections. Therefore, for most DCF analyses, and particularly if the NPV is at or near zero, it is desirable to conduct sensitivity analysis. The circumstances of each case will determine which variables are candidates for sensitivity analysis.

There are two methods that can be used in a discounted cash flow analysis: the weighted average cost of capital method (WACC), or the cost of equity method. The basic difference between the two methods centers around whether the discount rate represents the weighted average cost of capital or the cost of equity. The weighted average cost of capital uses a discount rate that represents the combined cost of debt and equity. Because the discount rate for the WACC includes the cost of debt, there are no explicit interest payments. Because the original investment represents both debt and equity, there are no explicit principal payments. In the cost of equity method, the discount rate represents only the cost of equity. Therefore, interest payments on debt are identified explicitly. Also, the original investment represents only the equity share of the original investment, and, as a result, the debt portion of the original investment is considered through regular principal repayments.

The analyst should consider supplementing NPV analysis with other techniques such as ROI, internal rate of return (IRR), payback, and so on. For example, if a given industry normally relies on ROI to make decisions, then an ROI analysis, in addition to a DCF analysis, may be desirable in order to use the same technique that industry uses to make decisions. Internal rate of return is an analytical technique similar to NPV. The difference between IRR and NPV is in the discounting of the cash

Table A.14. Discounted Cash Flow Analysis
(Dollars in Thousands)

Financing: 100% Equity

	Year 1	2	3	4	5	6	7	8	9	10
1. Revenue	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
2. Cost	700	700	700	700	700	700	700	700	700	700
3. Depreciation	100	100	100	100	100	100	100	100	100	100
4. Interest	0	0	0	0	0	0	0	0	0	0
5. Control O&M Cost	0	0	0	0	0	0	0	0	0	0
6. Control Depreciation	0	0	0	0	0	0	0	0	0	0
7. Control Interest	0	0	0	0	0	0	0	0	0	0
8. Earnings Before Tax	200	200	200	200	200	200	200	200	200	200
9. Depletion	0	0	0	0	0	0	0	0	0	0
10. Tax Liability	100	100	100	100	100	100	100	100	100	100
11. Investment Tax Credit	50	50	0	0	0	0	0	0	0	0
12. Control Investment Tax Credit	0	0	0	0	0	0	0	0	0	0
13. Minimum Tax	0	0	0	0	0	0	0	0	0	0
14. Total Tax Due	50	50	100	100	100	100	100	100	100	100
15. Earnings After Tax	150	150	100	100	100	100	100	100	100	100
16. Depreciation	100	100	100	100	100	100	100	100	100	100
17. Control Depreciation	0	0	0	0	0	0	0	0	0	0
18. Depletion	0	0	0	0	0	0	0	0	0	0
19. Cash Flow Before Deduction	250	250	200	200	200	200	200	200	200	200
20. Principal Payments	0	0	0	0	0	0	0	0	0	0
21. Control Principal Payments	0	0	0	0	0	0	0	0	0	0
22. Sustaining Capital Expenditures	0	0	0	0	0	0	0	0	0	0
23. Net Cash Flow	250	250	200	200	200	200	200	200	200	200
24. Discount Factor	.909	.826	.751	.683	.621	.564	.513	.467	.424	.386
25. Discounted Net Cash Flow	227.3	206.5	150.2	136.6	124.2	112.8	102.6	93.4	84.8	77.2

Present Value of Cash Flows	1,315.6
Original Investment	- 1,000.0
Net Present Value	+ 315.6

flows. The NPV calculation discounts the cash flows at a predetermined discount rate, whereas IRR seeks that discount rate which yields an NPV equal to zero. After the IRR for an investment project is calculated, the firm's cost of capital is compared to the IRR for the investment project. If the IRR is greater than or equal to the firm's cost of capital, the project should be accepted. If the IRR is less than the firm's cost of capital, the project should be rejected. The payback period is an example of another analytical technique that should be considered as a potential supplement to a DCF analysis. The value of considering payback as a supplement to DCF is that DCF does not specifically identify the point in time that a project breaks even. Overall, DCF analysis is the most comprehensive technique.

A.6 Mill Closure Methodology

To determine the potential for uranium mills to close due to tailings disposal costs, we have performed a discounted cash flow analysis. This section describes the methodology in detail. The analysis is performed for each economic impact case and each model mill. The results of the analysis are presented in the next section.

Table A.15 shows an example of the DCF calculations for a small mill with a 7 million MT tailings pile, with 5 years remaining lifetime and subject to the control costs of Case M_2. The first step in determining the cash flow is to project the annual quantity of U_3O_8 to be produced over the remaining lifetime of the mill. Production is based on the mill's capacity, the capacity utilization rate, the ore grade (assumed to be .1 percent), and the uranium recovery factor (assumed to be 93 percent). Production is expressed in terms of pounds of U_3O_8 (line 1). The capacity utilization rate used in the mill closure analysis is the industry average rate derived in the industry simulation described in Appendix B. This utilization rate projection is applied uniformly to each mill and for each impact case. The projected rate is 85 percent for 1980 (year 1), 65 percent for 1981-82, 70 percent for 1983, 80 percent for 1984, 85 percent for 1985, 90 percent for 1982-92, and 85 percent for 1993-94 (year 15). An alternative utilization rate - a constant 85 percent - was also considered, but the varying rate was adopted in order to be conservative and consistent with the industry average rates used in Appendix B.

The forecast of uranium price (line 2) was derived from DOE data sources and is explained in Chapter 2 and Appendix B. The ability of companies to pass-through disposal costs in terms of price increases is also considered in the DCF analysis (line 3). Total revenue (line 4) to the mill is derived by multiplying the uranium price (line 2 and line 3) by the production (line 1). The mill's cash flow (line 6) is estimated by multiplying the revenue estimated (line 4) by the assumed cash flow margin (line 5).

Table A.15. Discounted Cash Flow Analysis - CASE M_2
Small Mill, 7 Million MT Pile, 5 Years Remaining
(1981 Dollars)

	YEAR				
	1	2	3	4	5
1. U_3O_8 Production (Million lbs.)	0.56	0.43	0.43	0.46	0.53
2. U_3O_8 Price ($/lb)	29.31	30.69	32.07	33.45	34.83
3. Price Pass-through ($/lb)	0.00	0.00	0.00	0.00	0.00
4. Revenue (Million $)	16.4	13.2	13.8	15.5	18.4
5. Cash Flow Margin	0.20	0.20	0.20	0.20	0.20
6. Cash Inflow (Million $)	3.29	2.63	2.75	3.09	3.68
7. Control Costs-Existing Tailings (Million $)	2.28	2.28	2.28	2.28	2.28
8. Control Costs-New Tailings (Million $)	1.17	0.89	0.89	0.96	1.10
9. Net Cash Flow (Million $)	-0.16	-0.54	-0.42	-0.15	0.30
10. Discount Factor	.9091	.8265	.7513	.6830	.6209
11. Discounted Net Cash Flow (Million $)	-0.14	-0.45	-0.32	-0.10	0.19

12. Net Present Value (Million $) = -0.82

To determine the appropriate cash flow margin - the percent of revenues that is considered cash flow - we relied on the financial data of six companies in the uranium industry. These data are shown in Tables A.16 and A.17. As a group, these six companies provide a reasonable financial representation of the uranium industry. Although there are other companies in the industry, the financial results for those other companies contain insufficient information about uranium, or the results are not representative of the uranium industry. For example, Exxon Corporation and Union Carbide Corporation both have uranium operations, but the financial results of their uranium operations are a small part of the total company and are not identifiable from company financial statements.

The financial information has been assembled from corporate annual reports and Securities and Exchange Commission (SEC) 10-K reports. Many companies in the uranium industry have more than one business segment. The information shown in Tables A.16 and A.17 is for the business segment that includes uranium, although in many instances other products may also be included in the uranium business segment, such as other metals. Therefore, results should be compared over several years and among several companies for the results to be considered typical of the uranium industry.

For the purpose of this analysis, pre-tax cash flow generated from mill revenues is used to focus on the cash available to meet additional expenditures required for control of the tailings. Table A.17 has shown the industry ratios for the components of pre-tax cash flow. A cash flow margin of 20 percent on revenue is used (15 percent operating profit plus 5 percent depreciation and depletion). A cash flow margin of 20 percent is used to represent an average margin over the life of a project. Depreciation and depletion are frequently 10 percent or more; however, the excess above 5 percent is assumed to be committed to debt repayment or sustaining capital expenditures, or both. The principal difference between cash flow and operating profit is that cash flow includes depreciation and depletion, whereas operating profit does not. Depreciation and depletion are expenses for income tax calculations, but they are not cash expenses.

Annual control costs for each model mill are estimated separately for existing tailings and new tailings (see Table A.15). For existing tailings, the model pile costs of Table A.5 are spread equally over the first five years for all model mills (line 7). For new tailings, the annual control cost (line 8) is derived by multiplying the appropriate unit disposal cost from Table A.6 (converted to dollars per pound of U_3O_8) by the annual production estimate (line 1).

After the control costs are estimated, the net cash flow for each year can be calculated. The net cash flow (line 9) equals the cash flow (line 6) minus the control costs (line 7 and line 8). A discount factor (10 percent discount rate is assumed) (line 10) is then applied to the net cash flow (line 9) to give the discounted net cash flow (line 11). The sum of the annual discounted net cash flow estimates yields the net present value (line 12).

Table A.16. Financial Information for Selected Companies in the Uranium Industry ($ in Thousands)

	Year	Atlas	Conoco	Homestake	Kerr-McGee	Pioneer	UNC
Revenues	1976	15,611	NA	22,441	96,800	NA	29,339
	1977	28,152	NA	59,141	123,300	NA	80,816
	1978	26,845	16,488	44,928	115,200	13,810	133,193
	1979	38,253	16,384	42,388	163,400	20,267	181,626
	1980	60,148	34,586	45,363	238,900	7,829	167,811
Operating Profit	1976	4,607	NA	10,389	32,700	NA	7,103
	1977	8,027	NA	24,622	22,300	NA	28,539
	1978	(1,925)	(20,815)	20,454	20,100	1,257	42,320
	1979	(2,159)	(21,530)	14,097	(200)	(1,004)	61,339
	1980	6,142	(30,719)	(601)(a)	30,000	(1,082)	12,243
Assets	1976	NA	NA	14,144	215,300	NA	87,222
	1977	NA	NA	45,023	236,500	NA	145,376
	1978	56,375	52,491	42,990	272,000	51,119	203,041
	1979	79,428	61,218	47,790	288,400	70,583	279,436
	1980	72,834	62,867	54,798	304,800	84,046	239,888
Depreciation Depletion	1976	NA	NA	192	7,500	NA	1,070
	1977	NA	NA	80	9,300	NA	1,952
	1978	3,331	2,876	0	13,800	8,679	5,414
	1979	4,058	3,209	17	15,600	11,253	9,677
	1980	6,212	3,957	6,980	21,300	8,718	11,952
Capital Expend.	1976	NA	NA	2,036	NA	NA	27,856
	1977	NA	NA	2,628	NA	NA	54,499
	1978	14,579	7,213	7,961	NA	19,467	49,518
	1979	21,870	6,937	8,533	NA	23,513	39,156
	1980	7,453	7,999	12,521	NA	17,567	46,662

NA = Not Available.

(a) Includes an $8,075 loss on settlement of uranium litigation, would otherwise have been (8,075)-601 = +$7,474.

Table A.17. Financial Ratios for Selected Companies in the Uranium Industry (Percents)

	Year	Atlas	Conoco	Homestake	Kerr-McGee	Pioneer	UNC
Operating Profit/ Revenue	1976	29.5	NA	46.3	33.8	NA	24.2
	1977	28.5	NA	41.6	18.1	NA	35.3
	1978	-	-	45.5	17.4	9.1	31.8
	1979	-	-	33.3	-	-	33.8
	1980	10.2	-	16.5(a)	12.6	-	7.3
Operating Profit/ Assets	1976	NA	NA	73.4	15.2	NA	8.1
	1977	NA	NA	54.7	9.4	NA	19.6
	1978	-	-	47.6	7.4	2.5	20.8
	1979	-	-	29.5	-	-	22.0
	1980	8.4	-	13.6(b)	9.8	-	5.1
Depreciation Depletion/ Revenues	1976	NA	NA	1.8	7.7	NA	3.6
	1977	NA	NA	.3	7.5	NA	2.4
	1978	12.4	17.4	-	12.0	62.8	4.1
	1979	10.6	19.6	.04	9.5	55.5	5.3
	1980	10.3	11.4	15.4	8.9	111.0	7.1
Capital Expenditure/ Revenue	1976	NA	NA	9.1	NA	NA	95.0
	1977	NA	NA	4.4	NA	NA	67.4
	1978	54.3	43.7	17.7	NA	141.0	37.2
	1979	57.2	42.3	20.1	NA	116.0	21.6
	1980	12.4	23.1	27.6	NA	224.0	27.8

NA = Not Available.

- = Loss Year.

(a)16.5% without litigation.

(b)13.6% without litigation.

As discussed in Section A.5, if the net present value (NPV) of the cash flows is positive, then the project should be accepted or, in this case, the mill should remain open. If the NPV is negative, the mill should close. For conservatism, we have assumed for this analysis that if the NPV is less than $1 million, then the mill would cease operation.

Tables A.18a, A.18b, and A.18c present the estimated net present values for all 22 economic impact cases and each model mill, for the baseline industry demand scenario (each demand scenario has a different uranium price forecast which yields different cash flow estimates).

A.7 Mill Closure Results

The model mill closure determinations are based on the estimates of the net present value of the cash flows. The results for each economic impact case under the baseline industry demand scenario are summarized below. These results assume a cash flow margin of 20 percent and complete cost absorption by the model mills. Because there are three different sizes of model mills, the results are converted to the common denominator of equivalent number of small mills to allow direct comparison of different cases. Based on mill capacity, one medium mill is equivalent to two small mills, and one large mill is equivalent to three small mills. Thus, the total of 21 mills in the industry can be converted to the equivalent of 41 small mills [(7 small mills x 1) + (8 medium mills x 2) + (6 large mills x 3) = 41 small mill equivalents].

Economic Impact Case	Model Mill Closures	Equivalent Number of Small Mills
A, B, C, D, E, F H_1, H_2, I, J, K	No Closures	0
H_3, M_1, M_2, M_3	1 Small	1
G	2 Small	2
H_4	1 Small, 1 Large	4
L, M_4	2 Small, 1 Large	5
N	5 Small, 1 Medium, 3 Large	16

A.8 Sensitivity Analysis

To supplement the above closure results, a sensitivity analysis was performed which varied three parameters: the cash flow margin, the demand scenario, and the assumption of complete cost absorption by the model mills. The cash flow margin is varied from 20 percent to 25 percent, and then 15 percent. Two industry demand scenarios are presented for each cash flow margin: a baseline industry demand scenario and a low growth industry demand scenario. The low growth industry demand scenario

Table A.18a. Net Present Value for a Small Model Existing Mill
Baseline Industry Demand Scenario
(millions of 1981 dollars)

Economic Impact Case	900 MT ore/day					
	2(a)			7(a)		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
Number of Mills	1	1	1	1	0	3
A	11.63	22.31	30.07	11.63	22.31	30.07
B_1	11.63	22.31	30.07	11.63	22.31	30.07
B_2	11.63	22.31	30.07	11.63	22.31	30.07
B_3	11.63	22.31	30.07	11.63	22.31	30.07
C	8.33	18.75	26.34	6.96	17.39	24.98
D	8.33	18.75	26.34	6.96	17.39	24.98
E	8.21	18.49	25.99	5.78	16.06	23.56
F	8.21	18.49	25.99	5.78	16.06	23.56
G	0.99	10.98	18.30	-2.49	7.49	14.82
H_1	5.62	15.72	23.12	2.21	12.31	19.70
H_2	5.62	15.72	23.12	2.21	12.31	19.70
H_3	4.78	14.64	21.89	0.00	9.87	17.12
H_4	1.18	10.79	17.89	-4.88	4.73	11.82
I	7.82	15.64	21.63	7.82	15.64	21.63
J	4.87	12.68	18.67	3.50	11.32	17.30
K	5.19	13.19	19.29	2.76	10.76	16.86
L	-1.88	5.94	11.92	-5.37	2.45	8.43
M_1	2.84	10.84	16.94	-0.58	7.43	13.53
M_2	2.59	10.41	16.40	-0.82	7.00	12.98
M_3	2.06	9.88	15.86	-2.72	5.10	11.09
M_4	-2.06	5.11	10.69	-8.13	-0.96	4.63
N	-1.58	6.24	12.23	-25.31	-17.49	-11.51

(a) Size of existing tailings pile, million MT.

Table A.18b. Net Present Value for a Medium Model Existing Mill
Baseline Industry Demand Scenario
(millions of 1981 dollars)

Economic Impact Case	1,800 MT ore/day					
	2(a)			7(a)		
	5 Years	10 Years	15 Years	5 Years	10 Years	15 Years
Number of Mills	1	1	2	0	1	3
A	23.26	44.63	60.14	23.26	44.63	60.14
B_1	23.26	44.63	60.14	23.26	44.63	60.14
B_2	23.26	44.63	60.14	23.26	44.63	60.14
B_3	23.26	44.63	60.14	23.26	44.63	60.14
C	19.61	40.46	55.65	18.24	39.09	54.28
D	19.61	40.46	55.65	18.24	39.09	54.28
E	19.30	39.85	54.86	16.87	37.43	52.44
F	19.30	39.85	54.86	16.87	37.43	52.44
G	11.69	31.66	46.31	8.21	28.18	42.82
H_1	16.47	36.67	51.46	13.06	33.26	48.05
H_2	16.47	36.67	51.46	13.06	33.26	48.05
H_3	15.32	35.05	49.55	10.54	30.27	44.77
H_4	11.38	30.61	44.79	5.32	24.54	38.73
I	15.65	31.28	43.25	15.65	31.28	43.25
J	12.69	28.32	40.30	11.32	26.96	38.93
K	13.25	29.26	41.46	10.83	26.83	39.03
L	5.94	21.58	33.55	2.45	18.09	30.06
M_1	10.90	26.91	39.11	7.49	23.50	35.69
M_2	10.41	26.05	38.02	7.00	22.64	34.61
M_3	9.88	25.52	37.49	5.11	20.74	32.71
M_4	4.90	19.24	30.41	-1.16	13.17	24.34
N	6.24	21.88	33.85	-17.49	-1.85	10.12

(a) Size of existing tailings pile, million MT.

Table A.18c. Net Present Value for a Large Model Existing Mill Baseline Industry Demand Scenario (millions of 1981 dollars)

Economic Impact Case	2,700 MT ore/day								
	2(a)			7(a)			20(a)		
	5 Yrs	10 Yrs	15 Yrs	5 Yrs	10 Yrs	15 Yrs	5 Yrs	10 Yrs	15 Yrs
Number of Mills	0	0	1	0	1	1	1	0	2
A	34.88	66.94	90.21	34.88	66.94	90.21	34.88	66.94	90.21
B_1	34.88	66.94	90.21	34.88	66.94	90.21	34.88	66.94	90.21
B_2	34.88	66.94	90.21	34.88	66.94	90.21	34.88	66.94	90.21
B_3	34.88	66.94	90.21	34.88	66.94	90.21	34.88	66.94	90.21
C	30.89	62.16	84.95	29.52	60.80	83.58	25.43	56.70	79.49
D	30.89	62.16	84.95	29.52	60.80	83.58	25.43	56.70	79.49
E	30.38	61.22	83.74	27.96	58.79	81.31	22.35	53.18	75.70
F	30.38	61.22	83.74	27.96	58.79	81.31	22.35	53.18	75.70
G	22.39	52.35	74.32	18.90	48.86	70.83	7.46	37.41	59.38
H_1	27.32	57.63	79.81	23.91	54.22	76.40	15.65	45.95	68.14
H_2	27.32	57.63	79.81	23.91	54.22	76.40	15.65	45.95	68.14
H_3	25.86	55.46	77.21	21.08	50.68	72.43	9.48	39.08	60.83
H_4	21.59	50.42	71.70	15.52	44.36	65.64	-0.17	28.66	49.94
I	23.47	46.92	64.88	23.47	46.92	64.88	23.47	46.92	64.88
J	20.51	43.97	61.92	19.15	42.60	60.56	15.05	38.51	56.46
K	21.32	45.33	63.63	18.89	42.90	61.20	13.28	37.29	55.59
L	13.76	37.22	55.17	10.28	33.73	51.69	-1.17	22.28	40.24
M_1	18.97	42.98	61.28	15.56	39.57	57.86	7.30	31.30	49.60
M_2	18.24	41.69	59.65	14.83	38.28	56.24	6.56	30.01	47.97
M_3	17.71	41.16	59.12	12.93	36.38	54.34	1.33	24.78	42.74
M_4	11.86	33.37	50.13	5.80	27.31	44.06	-9.90	11.61	28.37
N	14.07	37.52	55.48	-9.66	13.79	31.75	-72.97	-49.52	-31.56

(a)Size of existing tailings pile, million MT.

includes prices that are lower and, consequently, cash flows that are lower than the baseline. Finally, the assumption of complete cost absorption by the model mills is varied.

The assumption of complete cost absorption has the greatest economic impact on the model mills. If the control costs can be completely or partially passed-through in the form of price increases, this will lessen the impact on the mills. Some pass-through is probable for several reasons. First, all of the existing mills plus any new mills will be subject to control costs. Therefore, although there may be different levels of control costs within the industry, the industry as a whole should pass-through control costs to some extent. Second, as discussed in Appendix B, demand for yellowcake is inelastic with respect to price. Finally, long-term contracts for U_3O_8 frequently contain cost escalation clauses. Two pass-through scenarios were analyzed: a $1 and $2 per pound increase in the price of U_3O_8.

Table A.19 presents the results of the sensitivity analysis for each economic impact case. There are 18 different scenarios which have been analyzed (2 demand projections x 3 cash flow margins x 3 cost absorption/pass-through assumptions). Since there are 22 economic impact cases, this yields 396 separate mill closure results, all of which are expressed in this table in terms of small mill equivalents. The findings of this analysis are discussed below.

Demand Projections

There is virtually no difference in mill closures associated with the different demand projections. Of the 198 estimations (22 impact cases x 3 cash flow margins x 3 cost absorption/pass-through assumptions) calculated for each demand projecton, only 2 show different results. For Case M_4 with a $1 cost pass-through and a 15 percent cash flow margin, the baseline demand results in 5 small mill equivalent closures, while there are 8 for the low-growth projection. Case N results in 7 small mill closures for $1 cost pass-through and 25 percent cash flow margin under the baseline demand projection, while there are 13 small mill closures for the low-growth demand. All the other cases result in the same number of closures for the baseline demand as they do for the low-growth demand.

The reason that the closure analysis is insensitive to the demand projection is that the price forecast for each projection is the same for 1980 through 1987, or the first eight years of the mill closure analysis (see Appendix B for a discussion of the price forecast for each demand projection). Consequently, there is no difference in the cash flows for model mills with a five-year remaining lifetime. Mills with a ten-year lifetime will have different cash flows only in years 9 and 10, while mills with a 15-year lifetime will have different cash flows for years 9 through 15. Since the cash flows are discounted, the few years in which they may be different due to the demand projection receive the least weight in determining the net present value of the cash flows. With the same or similar cash flow, the mill's decision to continue operating is basically unaffected by the demand projection.

Table A.19. Summary of Model Mill Closure Results(a)

Impact Case	Cost Absorption						$1 Price Increase (Cost Pass-Through)						$2 Price Increase (Cost Pass-through)					
	Baseline			Low Growth			Baseline			Low Growth			Baseline			Low Growth		
	25%	20%	15%	25%	20%	15%	25%	20%	15%	25%	20%	15%	25%	20%	15%	25%	20%	15%
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B_1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B_2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B_3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	1	2	5	1	2	5	0	1	2	0	1	2	0	0	1	0	0	1
H_1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
H_2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
H_3	0	1	4	0	1	4	0	0	1	0	0	1	0	0	1	0	0	1
H_4	1	4	5	1	4	5	1	1	5	1	1	5	0	1	1	0	1	1
I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
L	1	5	11	1	5	11	1	2	5	1	2	5	0	1	2	0	1	2
M_1	0	1	5	0	1	5	0	0	1	0	0	1	0	0	1	0	0	1
M_2	0	1	5	0	1	5	0	0	1	0	0	1	0	0	1	0	0	1
M_3	1	1	5	1	1	5	0	1	5	0	1	5	0	1	1	0	1	1
M_4	5	5	11	5	5	11	1	5	5	1	5	8	1	1	5	1	1	5
N	13	16	28	13	16	28	7	14	16	13	14	16	4	13	16	4	13	16

(a) Expressed in terms of small mill equivalents.

Cash Flow Margin

Selection of the cash flow margin has a noticeable impact on the mill closure analysis. For the cost absorption scenario, almost all the impact cases which show mill closures for a 20 percent cash flow margin have fewer closures with a 25 percent margin and more closures with a 15 percent margin. Four of the impact cases which have no closures under a 20 percent margin have one closure with a 15 percent margin.

Cost Absorption/Pass-Through Assumptions

The cost absorption/pass-through assumption also influences the mill closure analysis. Under the conditions of baseline demand and 20 percent cash flow margin, all but two of the impact cases which indicate closures with the cost absorption asumption have fewer closures with a $1 per pound pass-through. A $2 per pound pass-through reduces the closures even further for most cases.

REFERENCES FOR APPENDIX A

EMJ79	Engineering and Mining Journal, July 1979, Page 173.
NRC80	U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, September 1980.

APPENDIX B

PROJECTIONS OF PRICE, DEMAND, PRODUCTION

Appendix B

Projections of Price, Demand, Production

B.1 Introduction

The purpose of this appendix is to present the projections of the demand, price, and production of uranium for the years 1980 through 2000. The principal use of uranium is for generating electricity at nuclear power plants. Therefore, the demand for uranium is directly dependent on the total demand for electricity in general, and in particular, the demand for electricity generated by nuclear power.

B.2 Price and Demand

B.2.1 Baseline Industry Demand Scenario

Table B.1 presents projections of the demand for nuclear reactor generating capacity, the total amount of uranium that will be required to meet that generating capacity, the amount of uranium that will be provided by conventional mills, and the price of uranium. The projections of nuclear generating capacity and the price of uranium are both U.S. Department of Energy estimates based on their mid-range nuclear generating capacity scenario (DOE80). We refer to this scenario as the baseline industry demand scenario.

The assumptions underlying the projections for DOE's mid-range scenario are outlined in the DOE/EIA 1980 Annual Report to Congress and are summarized below. These assumptions reflect:

- A clear indication of increased demand for new electric generating capacity;
- A major reassessment of utility financial practices and utility rate structures to relieve debt-equity and cash-flow burdens of new nuclear construction;
- A resolution of uncertainties surrounding nuclear deployment, including the predictability of the licensing process, nuclear safety regulations, reactor siting, and long-term uranium availability;
- A resolution of the nuclear waste disposal problem, particularly the construction of a Federal repository for the long-term disposition of highly radioactive wastes.

Table B.1. Projections of Uranium Demand and Price, Baseline Industry Demand Scenario

Year	Reactor Capacity[a] (GWe)	Uranium Requirements (10^3 MT U_3O_8)	Conventional Share[b]	Conventional Demand (10^3 MT U_3O_8)	Uranium Price[c] (\$/lb U_3O_8)
1980	54.0	14.2	.884	12.5	29.31
1981	60.7	15.9	.856	13.6	30.69
1982	68.2	17.8	.835	14.9	32.07
1983	76.7	18.8	.816	15.3	33.45
1984	86.2	19.9	.805	16.0	34.83
1985	96.0	21.0	.790	16.6	36.20
1986	101.6	22.3	.776	17.3	37.58
1987	107.5	23.7	.758	18.0	38.96
1988	113.7	24.3	.737	17.9	40.33
1989	120.3	24.9	.719	17.9	41.72
1990	128.0	25.5	.714	18.2	43.09
1991	131.2	26.1	.716	18.7	44.47
1992	134.5	26.8	.717	19.2	45.85
1993	137.8	27.9	.728	20.3	47.22
1994	141.3	29.0	.738	21.4	48.61
1995	145.0	30.1	.747	22.5	49.98
1996	150.7	31.3	.752	23.5	51.35
1997	156.5	32.4	.760	24.6	52.74
1998	162.6	33.6	.767	25.8	54.11
1999	169.0	34.9	.775	27.0	55.50
2000	175.0	36.2	.784	28.4	56.87

[a] Linear interpolation estimates from an incomplete data series.

[b] Ratio of conventional milling to total milling.

[c] Linear regression estimates for an incomplete data series. The ordinary least squares equation used for estimation is: Price = - 2515 + 1.284 (Year). Prices were updated to 1981 using the Marshall & Swift equipment cost index for mining, milling (1979 to 1981 = 17.7%).

These general assumptions are quantified as follows:

- 154 nuclear power generating plants (or 145 GWe capacity) will be on line by 1995;
- The growth rate of electricity demand will approximate the estimated 2.5 percent growth in GNP for the period from 1980 to 2000.

  This estimate is further broken down into the following time periods:

1978 - 1985	2.8%
1985 - 1995	3.3%
1995 - 2020	2.0%

- Nuclear energy is projected to generate 26 percent of the electricity produced in the year 2000.

The price projections are estimated by the EUREKA Model which was designed specifically for modeling the price and supply of uranium (Ro81). The forecast represents an average of spot market and contract uranium prices. The price projections are "full recovery cost" estimates which are derived from the total costs associated with the recovery of known uranium reserves. These costs include production costs, sunk costs, taxes, and return on investment. The latter three costs distinguish the "full recovery cost" estimates from other types of forward cost estimates.

Converting the demand for generating capacity into uranium requirements is based on the assumptions used in the NRC Generic Environmental Impact Statement on uranium milling (NRC80):

> "Conversion from GWe to uranium requirements is based on an average of 185 MT U_3O_8 in yellowcake required per GWe-year. This is the factor for 3.0% reload enrichment, 0.20% enrichment tails, and an effective average plant capacity factor of 75%. A three-year delay between yellowcake production and fuel utilization is assumed."

Not all uranium is produced by conventional mills. In 1979, 88 percent of total uranium production was produced by conventional mills. The remaining 12 percent was produced by in-situ mining, phosphoric acid by-product operations, and heap leaching. Because this analysis is only concerned with conventional milling, it is therefore necessary to estimate the amount of uranium that will be produced by conventional milling versus unconventional milling. We used the projected ratio of conventional milling to total milling which was assumed in the NRC GEIS (NRC80). We estimated the demand for conventional milling production by multiplying the total uranium requirements by the conventional milling ratio.

Over the entire forecast period, the demand for uranium produced at conventional mills more than doubles from its 1980 level of 12,500 MT to 28,400 MT by the year 2000. The price of uranium is also projected to increase significantly from its 1980 level of $29.31 per pound of yellowcake to $56.87 per pound in the year 2000.

B.2.2 Low Growth Industry Demand Scenario

In addition to the baseline industry demand scenario, we studied a second case which requires a significantly lower level of production at conventional uranium mills. This case, identified as the low-growth industry demand scenario, represents either a large reduction in the growth of installed reactor capacity or a heavy reliance on imported uranium. A very low projection of installed reactor capacity (DOE's firm nuclear base scenario) was used to develop this industry demand projection. Table B.2 presents the forecast of reactor capacity and the derived demand for uranium. The projections of uranium demand, both total and for conventional mills, were derived in the same manner as in the baseline scenario.

The assumptions upon which this reactor capacity forecast is based are also outlined in the DOE/EIA 1980 Annual Report to Congress (DOE80). This scenario assumes that:

- Light-water reactors will be phased out after a 30-year operating life;
- Only nuclear units currently under construction and at least 10 percent complete will be allowed to complete construction and enter service.

Because a yellowcake price forecast is unavailable from DOE/EIA for this scenario, we have developed our own. Conventional demand for the period 1980 to 1987 does not change significantly compared to those values appearing in Table B.1, so that the price for this period can also be assumed to remain the same. For the 1988 to 2000 period, estimates were calculated using a simple regression technique relating price to total demand.

For the low-growth scenario, the demand for conventionally milled uranium peaks in 1987 at 17,100 MT and then declines to 14,800 tons by the year 2000. The rebound in the price of uranium is much less than that projected for the baseline demand scenario. The price increases from $29.31 per pound of U_3O_8 in 1980 to a peak price of $39.75 per pound in 1992. The real uranium price decreases to $34.04 by the year 2000. These projections for the year 2000 compare to projections of 28,400 MT of U_3O_8 and $56.87 per pound under the baseline industry demand scenario.

Table B.2. Projections of Uranium Demand and Price, Low Growth Industry Demand Scenario

Year	Reactor Capacity[a] (GWe)	Uranium Requirements (10^3 MT U_3O_8)	Conventional Share[b]	Conventional Demand (10^3 MT U_3O_8)	Uranium Price[c] (\$/lb U_3O_8)
1980	54.0	14.2	.884	12.5	29.31
1981	60.7	15.9	.856	13.6	30.69
1982	68.2	17.8	.835	14.9	32.07
1983	76.7	18.6	.816	15.2	33.45
1984	86.2	19.6	.805	15.8	34.83
1985	96.0	20.6	.790	16.3	36.20
1986	100.8	21.6	.776	16.8	37.58
1987	105.8	22.6	.758	17.1	38.96
1988	111.1	22.7	.737	16.7	39.21
1989	116.7	22.8	.719	16.4	39.34
1990	122.0	22.9	.714	16.3	39.48
1991	122.6	23.0	.716	16.5	39.62
1992	123.2	23.1	.717	16.6	39.75
1993	123.8	22.9	.728	16.7	39.48
1994	124.5	22.8	.738	16.8	39.34
1995	125.0	22.6	.747	16.9	39.07
1996	124.0	22.4	.752	16.8	38.80
1997	123.0	22.2	.760	16.9	38.52
1998	122.0	21.0	.767	16.1	36.89
1999	121.0	19.9	.775	15.4	35.40
2000	120.0	18.9	.784	14.8	34.04

[a] Linear interpolation estimates from an incomplete data series.

[b] Ratio of conventional milling to total milling.

[c] Linear regression estimates for an incomplete data series. The ordinary least squares equation used for estimating price for the years 1988 to 2000 is: Price = 7.756 + 1.268 (Demand). Prices were updated to 1981 using the Marshall and Swift equipment cost index for mining, milling (1979 to 1981 = 17.7%).

B.3 Production, Inventory, and Mill Closure Estimates

Tables B.3 and B.4 present production and inventory projections for the baseline and low-growth industry demand scenarios. Uranium inventories are those inventories held by utilities, reactor manufacturers, and fuel fabricators and are reported by DOE to be 47,500 MT U_3O_8 as of January 1980. Estimates of premature mill closures (due to market conditions, not control costs) are calculated under the restrictive assumptions of inventory adjustment time, new capacity coming on line, and capacity utilization rates.

In each demand scenario, a six-year period of adjustment is assumed to be an appropriate time period for the industry to work off the abnormally high level of excess inventories present at the beginning of 1980. This period was chosen to represent an average among various possible choices. For example, one possible choice can be represented by a scenario of total production curtailment. In such a situation, the level of uranium inventories would decrease to a normal level of about 20,000 MT after two years of consumption. A normal level would be approximately one year's worth of consumption. The case of total production curtailment seems unlikely, and, therefore, is not used in this analysis. Another possible choice is a nine-year inventory adjustment period that was forecast by Nuexco Corp. (Wh81). This forecast is based on the assumption that the industry is unwilling to cut back production, continues to build further inventories until the end of 1983, and is able to bear the abnormally high carrying costs associated with the large inventories. A six-year adjustment period is chosen to represent a combination of elements of the different possible choices.

The exact amount of new capacity coming on line is difficult to estimate since decisions concerning start-up times are continually changing. According to DOE estimates, conventional mill capacity as of January 1980 was 44,500 MT of ore per day or about 18,000 MT of U_3O_8 per year. At the present time, the information available suggests no new capacity for 1980 and 1981, only 300 MT of U_3O_8 per year of new capacity for 1982 and 1983, and 600 MT of U_3O_8 for 1984 (DOE80). New capacity after 1984 will be added at a rate necessary to accommodate expanding consumption and an obsolescence rate of .047. The assumed obsolescence rate of .047 is based on an estimated average mill life expectancy of 21.3 years. Generally, the life expectancy of a mill is at least as long as the life of the surrounding ore deposits (Lo81). Based upon a sample of 11 mills, an average total life was calculated by adding the actual years of operation with the expected remaining life of the surrounding ore deposits. This calculation resulted in an average mill life expectancy of 21.3 years.

Table B.3. Production and Inventory Projections
Baseline Industry Demand Scenario
(Thousands of Metric Tons of U_3O_8)

	Demand	Begin Invent.	Begin Capacity	New Capacity	Obsolete Capacity[a]	Capacity Utilization Rate	Total Product.	Premature Closure	Ending Inventory[b]	Ending Capacity
1980	12.5	47.5	18.0	0	.8	.85	14.9	0	49.9	17.2
1981	13.6	49.9	17.2	0	.8	.65	10.8	.3	47.1	16.0
1982	14.9	47.1	16.0	.3	.8	.65	10.2	.3	42.4	15.3
1983	15.3	42.4	15.3	.3	.7	.70	10.5	.3	37.6	14.6
1984	16.0	37.6	14.6	.6	.7	.80	11.5	.3	33.1	14.2
1985	16.6	33.1	14.2	1.2	.7	.85	12.3	0	28.8	14.7
1986	17.3	28.8	14.7	1.8	.7	.90	13.7	0	25.2	15.8
1987	18.0	25.2	15.8	2.4	.7	.90	15.0	0	22.2	17.5
1988	17.9	22.2	17.5	2.7	.8	.90	16.6	0	20.9	19.4
1989	17.9	20.9	19.4	2.7	.9	.90	18.2	0	21.2	21.2
1990	18.2	21.2	21.2	2.7	1.0	.90	19.8	0	22.8	22.9
1991	18.7	22.8	22.9	2.7	1.1	.90	21.3	0	25.4	24.5
1992	19.2	25.4	24.5	2.7	1.2	.90	22.7	0	29.0	26.0
1993	20.3	29.0	26.0	2.7	1.2	.85	22.8	0	31.4	27.5
1994	21.4	31.4	27.5	2.7	1.3	.85	24.0	0	34.0	28.9
1995	22.5	34.0	28.9	2.7	1.4	.85	25.2	0	36.7	30.3
1996	23.5	36.7	30.3	3.0	1.4	.85	26.4	0	39.6	31.8
1997	24.6	39.6	31.8	3.0	1.5	.85	27.7	0	42.7	33.3
1998	25.8	42.7	33.3	3.0	1.6	.85	28.9	0	45.8	34.8
1999	27.0	45.8	34.8	3.0	1.6	.85	30.1	0	48.9	36.1
2000	28.4	48.9	36.1	3.0	1.7	.85	31.3	0	51.8	37.4

[a] Obsolescense rate is .047 of capacity.

[b] These estimates assume a neutral impact from imports and nonconventional production.

	Demand	Begin Invent.	Begin Capacity	New Capacity	Obsolete Capacity[a]	Capacity Utilization Rate	Total Product.	Premature Closure	Ending Inventory[b]	Ending Capacity
1980	12.5	47.5	18.0	0	.8	.85	14.9	0	49.9	17.2
1981	13.6	49.9	17.2	0	.8	.65	10.8	.3	47.1	16.0
1982	14.9	47.1	16.0	.3	.8	.65	10.2	.3	42.4	15.3
1983	15.2	42.4	15.3	.3	.7	.70	10.5	.3	37.7	14.6
1984	15.8	37.7	14.6	.6	.7	.80	11.5	.3	33.4	14.2
1985	16.3	33.4	14.2	1.2	.7	.85	12.3	0	29.4	14.7
1986	16.8	29.4	14.7	1.5	.7	.90	13.6	0	26.2	15.5
1987	17.1	26.2	15.5	1.8	.7	.90	14.5	0	23.5	16.6
1988	16.7	23.5	16.6	1.8	.8	.90	15.4	0	22.2	17.6
1989	16.4	22.2	17.6	1.8	.8	.90	16.3	0	22.1	18.6
1990	16.3	22.1	18.6	1.8	.9	.90	17.1	0	23.0	19.5
1991	16.5	23.0	19.5	1.5	.9	.90	17.8	0	24.3	20.1
1992	16.6	24.3	20.1	1.5	.9	.90	18.3	0	26.1	20.7
1993	16.7	26.1	20.7	1.5	1.0	.85	17.8	0	27.1	21.2
1994	16.8	27.1	21.2	0.9	1.0	.85	18.0	0	28.3	21.1
1995	16.9	28.3	21.1	0.6	1.0	.85	17.8	0	29.2	20.7
1996	16.8	29.2	20.7	0.0	1.0	.85	17.2	0	29.5	19.7
1997	16.9	29.5	19.7	.6	.9	.85	16.6	0	29.3	19.4
1998	16.1	29.3	19.4	0	.9	.85	16.1	0	29.3	18.5
1999	15.4	29.3	18.5	0	.9	.85	15.3	0	29.2	17.6
2000	14.8	29.2	17.6	0	.8	.85	14.6	0	29.0	16.8

[a] Obsolescense rate is .047 of capacity.

[b] These estimates assume a neutral impact from imports and nonconventional production.

The capacity utilization rate (CUR) is assumed to fluctuate significantly over the first ten years. For the first five years, until inventories are decreased to an appropriate level, the CUR will be in the range of 0.65 to 0.85 (DOE80). The 0.65 level represents an average of current CUR's in the industry, and the 0.85 represents a historical CUR level for the industry (NRC80). An increase in the CUR to 0.90 for the next seven years is assumed so that the average for the entire forecast period approaches the historical level of 0.85 and inventory levels remain at near normal levels. The industry is capable of operating at rates of 0.90 and above during periods of tight supply. During the period 1976 through 1979, the industry operated at above historically normal rates, reaching a peak of 0.92 in 1978 (DOE79).

The methodology for estimating premature mill closures begins with the calculation of the ending capacity for each year. The formula for ending capacity is:

(1) $EC_t = BC_t\ (1 - ob) + NC_t - PC_t.$

Total production for the industry can be calculated by the following formula:

(2) $TP_t = CUR_t \times (BC_t + EC_t)/2.$

Finally, the ending inventory is calculated as follows:

(3) $EI_t = BI_t + (TP_t - D_t).$

where EC_t = Ending capacity in year t
BC_t = Beginning capacity in year t
ob = Obsolescence rate
NC_t = New capacity in year t
PC_t = Premature closures in year t
TP_t = Total production in year t
CUR_t = Capacity utilization rate in year t
EI_t = Ending inventory in year t
BI_t = Beginning inventory in year t
D_t = Conventional milling demand in year t.

Formula 1 estimates ending capacity for year t by adjusting beginning capacity in year t for the following three variables: (1) capacity which becomes obsolete during year t; (2) new capacity which begins production during year t; and (3) any premature closures during year t caused by any exogenous events. Formula 2 estimates total production for year t by averaging the beginning capacity with the ending capacity for year t and applying an appropriate capacity utilization rate for year t. The average capacity is used in order to account for new capacity or obsolete capacity which is in production for a fraction of year t. Formula 3 is an identity which calculates ending inventory in year t by adjusting beginning inventory for surplus (deficit) production in year t. These formulas were used in an iterative procedure until a series of premature closures were obtained which yielded an ending inventory level in 1986 that approached a normal level of one year's consumption.

The results from this procedure, presented in Tables B.3 and B.4, indicate premature closures of 300 MT of U_3O_8 capacity per year for four years, for a cumulative effect of 1200 MT U_3O_8 capacity. These premature mill closures do not necessarily represent permanent closures. The extreme inventory buildup, which forced the closures and reduced capacity utilization, is only a temporary phenomena. It is possible that after inventory equilibrium is achieved, these mills will be brought back on line and treated as new mills.

For both demand scenarios, Tables B.5 and B.6 present a summary of the projections of demand, production, inventory, and prices for conventional milling of U_3O_8. In addition, the projections of production are segmented by production from old and new capacity. The following formulas are used to make these calculations:

(4) $OC_t = EC_t$
when t = 1982 and years preceding 1982.

Equation 4 identifies old capacity in 1982 as identical to ending capacity in 1982.

(5) $OC_t = OC_{t-1} - 1/2\ (OB_t + PC_t)$
when t = 1983.

Equation 5 estimates old capacity in 1983 to be equal to old capacity in 1982 less any mill closures occurring in 1983 resulting from both premature closures and obsolete capacity. Only half of the mill closures occurring in 1983 will impact old production in 1983. The other half of 1983 mill closures is carried forward to the following year since the impact on production will begin in 1984.

(6) $OC_t = OC_{t-1} - 1/2\ (OB_{t-1} + PC_{t-1}) - 1/2\ (OB_t + PC_t)$
when t = 1984 through 2000.

Equation 6 estimates old capacity for the years 1984 through 2000 by employing the same methodology used in equation 5. However, an additional term $1/2\ (OB_{t-1} + PC_{t-1})$ occurred in the previous year but begins impacting production in the current year. For 1984, old capacity is estimated to be equal to old capacity in 1983 less half of the mill closures in 1983 and half of the mill closures in 1984.

Production from old capacity is calculated by:

(7) $OP_t = CUR_t \times OC_t$

New production is calculated by:

(8) $NP_t = TP_t - OP_t$

Table B.5. Summary Table of Projections of Demand, Production, and Uranium Price for Conventional Milling of U_3O_8, Baseline Industry Demand Scenario

	Conventional Demand[a]	Production[a]			Ending Inventory[a]	Price ($/lb U_3O_8)
		Total	Old	New		
1980	12.5	14.9	14.9	0	49.9	29.31
1981	13.6	10.8	10.8	0	47.1	30.69
1982	14.9	10.2	10.2	0	42.4	32.07
1983	15.3	10.5	10.3	.1	37.6	33.45
1984	16.0	11.5	11.0	.5	33.1	34.83
1985	16.6	12.3	11.0	1.3	28.8	36.20
1986	17.3	13.7	11.0	2.7	25.2	37.58
1987	18.0	15.0	10.4	4.6	22.2	38.96
1988	17.9	16.6	9.7	6.9	20.9	40.33
1989	17.9	18.2	8.9	9.3	21.2	41.72
1990	18.2	19.8	8.1	11.7	22.8	43.09
1991	18.7	21.3	7.1	14.2	25.4	44.47
1992	19.2	22.7	6.1	16.6	29.0	45.85
1993	20.3	22.8	4.8	18.0	31.4	47.22
1994	21.4	24.0	3.7	20.3	34.0	48.61
1995	22.5	25.2	2.6	22.6	36.7	49.98
1996	23.5	26.4	1.4	25.0	39.6	51.35
1997	24.6	27.7	0.2	27.5	42.7	52.74
1998	25.8	28.9	0	28.9	45.8	54.11
1999	27.0	30.1	0	30.1	48.9	55.50
2000	28.4	31.3	0	31.3	51.8	56.87

[a] Thousands of Metric Tons of U_3O_8.

Table B.6. Summary Table of Projections of Demand, Production, and Uranium Price for Conventional Milling of U_3O_8, Low-Growth Industry Demand Scenario

	Conventional Demand[a]	Production[a]			Ending Inventory[a]	Price ($/lb U_3O_8)
		Total	Old	New		
1980	12.5	14.9	14.9	0	49.9	29.31
1981	13.6	10.8	10.8	0	47.1	30.69
1982	14.9	10.2	10.2	0	42.4	32.07
1983	15.2	10.5	10.3	.1	37.7	33.45
1984	15.8	11.5	11.0	.5	33.4	34.83
1985	16.3	12.3	11.0	1.3	29.4	36.20
1986	16.8	13.6	11.0	2.6	26.2	37.58
1987	17.1	14.5	10.4	4.1	23.5	38.96
1988	16.7	15.4	9.7	5.7	22.2	39.21
1989	16.4	16.3	9.0	7.3	22.1	39.34
1990	16.3	17.1	8.2	8.9	23.6	39.48
1991	16.5	17.8	7.4	10.4	24.3	39.62
1992	16.6	18.3	6.6	11.7	26.1	39.75
1993	16.7	17.8	5.4	12.4	27.1	39.48
1994	16.8	18.0	4.6	13.4	28.3	39.34
1995	16.9	17.8	3.7	14.0	29.2	39.07
1996	16.8	17.2	2.9	14.3	29.5	38.80
1997	16.9	16.6	2.1	14.5	29.3	38.52
1998	16.1	16.1	1.3	14.8	29.3	36.89
1999	15.4	15.3	0.6	14.8	29.2	35.40
2000	14.8	14.6	0	14.6	29.0	34.04

[a] Thousands of Metric Tons of U_3O_8.

where OC_t = Old capacity in year t
OP_t = Old production in year t
CUR_t = Capacity utilization rate in year t
PC_t = Premature closures
OB_t = Obsolete old capacity in year t (set equal to .047 x BC_t)
NP_t = New production in year t
TP_t = Total production in year t.

B.4 Elasticity of Demand

A discussion on price elasticity of uranium deserves mention within the context of demand projections. The factors which normally affect the price elasticity of demand for any product are not significant in the case of uranium. First, the substitutes for uranium, such as oil, coal, and natural gas, are not cost competitive at the present time. Coal is the closest substitute to becoming cost competitive with uranium, but it is estimated that the price of yellowcake would have to approach $160 per pound (1980 dollars) before a breakeven would occur (Ni81).

Second, the price of yellowcake is a small part of the total cost of generating electricity. For the 1980 through 2000 forecast period, the portion of total nuclear power generation cost due to the cost of yellowcake is estimated to range from about 9.6 percent in 1980 to 13.5 percent in the year 2000 (Hu81). This slight increase is due solely to the increase in the price of yellowcake, ceteris paribus, all other costs of generation remaining constant over time. Based upon this information, this analysis assumes that the demand for yellowcake is perfectly inelastic in all scenarios presented.

B.5 Production and Inventory Impacts From Control Caused Closures

Appendix A presented an analysis of mill closures for each economic impact case. This section is intended to combine the mill closure results with the projections described above in order to determine the impacts these closures will have on production, inventories, and the requirements for new capacity. Table B.7 presents a summary of the mill closure analysis from Appendix A.

The mill closure estimates are stated in terms of annual U_3O_8 capacity, based on an equivalent small mill capacity of 300 MT U_3O_8 per year. The net capacity equivalent for these closures (see Table B.7) is estimated by subtracting the 1200 MT U_3O_8 capacity which, as discussed above, we estimate will close due to market conditions. The net capacity equivalent for the closures is added to the premature closures in Table B.3 for the year 1983, the year in which we assume both the standard will become effective and the decision to close will be made. New capacity is then adjusted accordingly so that inventory equilibrium will still be achieved in 1986 and production will be sufficient to meet demand through the year 2000.

Table B.7. Model Mill Closure Summary

	Baseline and Low-Growth Industry Demand Scenarios[a]				
Reg. Opt.	Model Mill Closures	No. of Small Mill Equivalents	Capacity Equivalent (MT U_3O_8)	Net No. of Small Mill Equivalents[b]	Net Capacity Equivalent (MT U_3O_8)
A	No Closures	-	-	-	-
B_1	No Closures	-	-	-	-
B_2	No Closures	-	-	-	-
B_3	No Closures	-	-	-	-
C	No Closures	-	-	-	-
D	No Closures	-	-	-	-
E	No Closures	-	-	-	-
F	No Closures	-	-	-	-
G	2 Small	2	600	-	-
H_1	No Closures	-	-	-	-
H_2	No Closures	-	-	-	-
H_3	1 Small	1	300	-	-
H_4	1 Small 1 Large	4	1200	-	-
I	No Closures	-	-	-	-
J	No Closures	-	-	-	-
K	No Closures	-	-	-	-
L	2 Small 1 Large	5	1500	1	300
M_1	1 Small	1	300	-	-
M_2	1 Small	1	300	-	-
M_3	1 Small	1	300	-	-
M_4	2 Small 1 Large	5	1500	1	300
N	5 Small 1 Medium 3 Large	16	4800	12	3600

[a] Estimated under conditions of 100 percent cost absorption and 20 percent cash flow margin. The results for both demand scenarios are the same for the 20% cash flow case.

[b] The net number of small mill equivalents is equal to the gross number of small mill equivalents minus the four small mill closures due to market conditions.

The adjustment procedure just outlined is a simplified simulation of a more realistic simultaneous adjustment process. A more likely situation would involve more than one variable changing in the adjustment process. For example, if an inventory increase (decrease) occurs, not only will the addition of new capacity decrease (increase), but it can be expected that the obsolescence rate will increase (decrease), the capacity utilization rate will decrease (increase), and more (less) premature closures will occur. The simultaneous adjustment process would allow the impact to be spread over many variables. The single variable adjustment process used in this analysis will overestimate the impact on additions to new capacity.

The mill closure analysis is complicated by the parameters of closure timing. In the DCF analysis of Appendix A, if mill closure appears justified, the timing is assumed to occur when the standard becomes effective, i.e., 1983. In reality, it is conceivable that some mills could operate longer if their yearly net cash flow exceeds the incremental yearly tailings control cost. This on-going situation arises because of the assumption that the mills are financially responsible for control of the existing tailings pile whether they close before or after the effective date of the standard. Facing such an obligation from the accumulated tailings piles, some mills could face less of a loss if they continued to operate. More detailed investigations of specific timing were felt to not be possible because such investigations would require individual mill information about marginal control cost curves and marginal production cost curves.

B.5.1 Baseline Industry Demand Scenario

As shown in Table B.7, only 3 of the 22 economic impact cases result in net mill closures, that is, closures which are greater than those which we estimate would take place anyway in the absence of any control costs due to market conditions. Thirteen of the cases result in no closures and, therefore, have no impact on the projections. The remaining 6 cases have closures but were not examined since the plant closure capacity equivalent is less than the premature closures due to market conditions (i.e., no net closures in Table B.7).

Cases L and M_4 indicate a reduction in capacity of five small model mill equivalents or 1,500 MT of U_3O_8. The impacts on the projections for these cases are shown in Table B.8. There is no impact on the introduction of new capacity. Demand is met by a slight reduction in inventory levels. Production at old mills is slightly lower than that which takes place in the no closure case.

The results for Case N -- a reduction in capacity of sixteen small model mill equivalents or 4800 MT of U_3O_8 -- are presented in Table B.9. The simulation under this option requires additional new capacity in each year from 1984 through 1990. The biggest increase from the no closure case is in 1985 where an additional 900 MT of U_3O_8 capacity is required. Inventory levels are also substantially reduced

Table B.8. Production and Inventory Projections - Cases L and M_4[a]
Baseline Industry Demand Scenario
(Thousands of Metric Tons of U_3O_8)

	Demand	Begin. Invent.	Begin. Capacity	New Capacity	Obsolete Capacity[b]	Capacity Utilization Rate	Production			Premature Closure[c]	Ending Inventory	Ending Capacity
							Total	Old	New			
1980	12.5	47.5	18.0	0	.8	.85	14.9	14.9	0	0	49.9	17.2
1981	13.6	49.9	17.2	0	.8	.65	10.8	10.8	0	.3	47.1	16.0
1982	14.9	47.1	16.0	.3	.8	.65	10.2	10.2	0	.3	42.4	15.3
1983	15.3	42.4	15.3	.3	.7	.70	10.3	10.2	0.1	.6	37.4	14.2
1984	16.0	37.4	14.2	.6	.7	.80	11.2	10.7	0.5	.3	32.6	13.8
1985	16.6	32.6	13.8	1.2	.6	.85	12.0	10.7	1.3	0	28.0	14.4
1986	17.3	28.0	14.4	1.8	.7	.90	13.4	10.7	2.7	0	24.0	15.5
1987	18.0	24.2	15.5	2.4	.7	.90	14.7	10.1	4.6	0	20.8	17.2
1988	17.9	20.8	17.2	2.7	.8	.90	16.3	9.4	6.9	0	19.2	19.1
1989	17.9	19.2	19.1	2.7	.9	.90	18.0	8.6	9.3	0	19.3	20.9
1990	18.2	19.3	20.9	2.7	1.0	.90	19.6	7.8	11.7	0	20.7	22.6
1991	18.7	20.7	22.6	2.7	1.1	.90	21.1	6.9	14.2	0	23.0	24.2
1992	19.2	23.0	24.2	2.7	1.1	.90	22.5	5.9	16.6	0	26.3	25.8
1993	20.3	26.3	25.8	2.7	1.2	.85	22.5	4.6	18.0	0	28.6	27.3
1994	21.4	28.6	27.3	2.7	1.3	.85	23.8	3.5	20.3	0	31.0	28.7
1995	22.5	31.0	28.7	2.7	1.3	.85	25.0	2.4	22.6	0	33.4	30.0
1996	23.5	33.4	30.0	3.0	1.4	.85	26.2	1.2	25.0	0	36.1	31.6
1997	24.6	36.1	31.6	3.0	1.5	.85	27.5	0	27.5	0	39.1	33.1
1998	25.8	39.1	33.1	3.0	1.6	.85	28.8	0	28.8	0	42.0	34.6
1999	27.0	42.0	34.6	3.0	1.6	.85	30.0	0	30.0	0	45.0	36.0
2000	28.4	45.0	36.0	3.0	1.7	.85	31.1	0	31.1	0	47.7	37.3

[a] These options include the closure of 2 small mills and 1 large mill which is approximately equal to 1.5 thousand metric tons. Net control-caused closures would be equal to 1.5 thousand metric tons minus 1.2 thousand metric tons of premature closure capacity.

[b] Obsolescence rate is .047 of capacity.

[c] Premature closures includes closures caused by control which are assumed to occur in 1983.

Table B.9. Production and Inventory Projections - Case N[a]
Baseline Industry Demand Scenario
(Thousands of Metric Tons of U_3O_8)

	Demand	Begin. Invent.	Begin. Capacity	New Capacity	Obsolete Capacity[b]	Capacity Utilization Rate	Production			Premature Closure[c]	Ending Inventory	Ending Capacity
							Total	Old	New			
1980	12.5	47.5	18.0	0	.8	.85	14.9	14.9	0	0	49.9	17.2
1981	13.6	49.9	17.2	0	.8	.65	10.8	10.8	0	.3	47.1	16.0
1982	14.9	47.1	16.0	.3	.8	.65	10.2	10.2	0	.3	42.4	15.3
1983	15.3	42.4	15.3	.3	.7	.70	9.1	9.0	0.1	3.9	36.2	10.7
1984	16.0	36.2	10.7	1.2[d]	.5	.80	8.7	8.0	0.7	.3	28.9	11.1
1985	16.6	28.9	11.1	2.1[d]	.5	.85	10.1	7.9	2.2	0	22.4	12.7
1986	17.3	22.4	12.7	2.4[d]	.6	.90	12.2	7.9	4.3	0	17.3	14.5
1987	18.0	17.3	14.5	2.7[d]	.7	.90	13.9	7.3	6.6	0	13.3	16.5
1988	17.9	13.3	16.5	3.0[d]	.8	.90	15.8	6.7	9.2	0	11.2	18.7
1989	17.9	11.2	18.7	3.0[d]	.9	.90	17.8	5.9	11.9	0	11.1	20.8
1990	18.2	11.1	20.8	3.0[d]	1.0	.90	19.7	5.1	14.6	0	12.5	22.9
1991	18.7	12.5	22.9	2.7	1.1	.90	21.3	4.2	17.1	0	15.1	24.5
1992	19.2	15.1	24.5	2.7	1.2	.90	22.7	3.2	19.6	0	18.7	26.0
1993	20.3	18.7	26.0	2.7	1.2	.85	22.8	2.0	20.8	0	21.1	27.5
1994	21.4	21.1	27.5	2.7	1.3	.85	24.0	0.9	23.1	0	23.7	28.9
1995	22.5	23.7	28.9	2.7	1.4	.85	25.1	0	25.1	0	26.4	30.3
1996	23.5	26.4	30.3	3.0	1.4	.85	26.4	0	26.4	0	29.2	31.8
1997	24.6	29.2	31.8	3.0	1.5	.85	27.7	0	27.7	0	32.3	33.3
1998	25.8	32.3	33.3	3.0	1.6	.85	28.9	0	28.9	0	35.5	34.8
1999	27.0	35.5	34.8	3.0	1.6	.85	30.1	0	30.1	0	38.6	36.1
2000	28.4	38.6	36.1	3.0	1.7	.85	31.3	0	31.3	0	41.5	37.4

[a] These options include the closure of 5 small mills, 1 medium mill, and 3 large mills, which is approximately equal to 4.8 thousand metric tons. Net control-caused closures would be equal to 4.8 thousand metric tons minus 1.2 thousand metric tons of premature closure capacity.

[b] Obsolescence rate is .047 of capacity.

[c] Premature closures includes closures caused by control which are assumed to occur in 1983.

[d] Includes new mill capacity additional to new capacity projected for the no closure case (Table B.3).

from the no closure case, reaching a low of 11,100 MT U_3O_8 in 1990 compared to a low of 20,900 MT in 1989. Total industry production is lower from 1983 through 1989 but is the same as that projected in the no closure case from 1990 to 2000. Production is shifted from old mills to new mills, as new mill production is higher from 1984 through 1997 than that projected in the no closure case.

B.5.2 Low-Growth Industry Demand Scenario

Tables B.10 and B.11 present the simulation results for the three cases which have net mill closures under the low-growth industry demand scenario. For Cases L and M_4 (Table B.10), which both result in closures of five small mill equivalents, there is a small increase in the new capacity projection for 1994 through 1996. Yearly inventory levels are slightly lower throughout the projection period than that of the no closure case. Total industry production is slightly higher from 1995 through 2000.

In Case N (Table B.11), which results in the closure of sixteen small mill equivalents, projections of new capacity are higher than in the no closure case for the years 1985 through 1990 and 1994 through 1996. Demand is met by a significant reduction in inventory levels. Inventories reach a low of 7000 MT of U_3O_8 in 1991, a 70 percent reduction in the minimum inventory level of 22,100 MT (in 1990) from the no closure case. Total industry production for this case is lower than the no closure case for the years 1983 through 1995 and higher from 1996 through the year 2000.

Table B.10. Production and Inventory Projections - Cases L and M_4[a]
Low-Growth Industry Demand Scenario
(Thousands of Metric Tons of U_3O_8)

	Demand	Begin. Invent.	Begin. Capacity	New Capacity	Obsolete Capacity[b]	Capacity Utilization Rate	Production			Premature Closure[c]	Ending Inventory	Ending Capacity
							Total	Old	New			
1980	12.5	47.5	18.0	0	.8	.85	14.9	14.9	0	0	49.9	17.2
1981	13.6	49.9	17.2	0	.8	.65	10.8	10.8	0	.3	47.1	16.0
1982	14.9	47.1	16.0	.3	.8	.65	10.2	10.2	0	.3	42.4	15.3
1983	15.2	42.4	15.3	.3	.7	.70	10.3	10.2	0.1	.6	37.5	14.2
1984	15.8	37.5	14.2	.6	.7	.80	11.2	10.7	0.5	.3	32.9	13.8
1985	16.3	32.9	13.8	1.2	.6	.85	12.0	10.7	1.3	0	28.6	14.4
1986	16.8	28.6	14.4	1.5	.7	.90	13.3	10.7	2.6	0	25.1	15.2
1987	17.1	25.1	15.2	1.8	.7	.90	14.2	10.1	4.1	0	22.2	16.3
1988	16.7	22.2	16.3	1.8	.8	.90	15.1	9.4	5.7	0	20.6	17.3
1989	16.4	20.6	17.3	1.8	.8	.90	16.0	8.7	7.3	0	20.2	18.3
1990	16.3	20.2	18.3	1.8	.9	.90	16.9	8.0	8.9	0	20.8	19.2
1991	16.5	20.8	19.2	1.5	.9	.90	17.6	7.2	10.4	0	21.9	19.8
1992	16.6	21.9	19.8	1.5	.9	.90	18.1	6.4	11.7	0	23.4	20.4
1993	16.7	23.4	20.4	1.5	1.0	.85	17.6	5.2	12.4	0	24.3	20.9
1994	16.8	24.3	20.9	1.2[d]	1.0	.85	17.9	4.4	13.5	0	25.4	21.2
1995	16.9	25.4	21.2	1.2[d]	1.0	.85	18.1	3.5	14.5	0	26.5	21.4
1996	16.8	26.5	21.4	0.3[d]	1.0	.85	17.9	2.7	15.2	0	27.6	20.7
1997	16.9	27.6	20.7	.6	1.0	.85	17.4	1.8	15.6	0	28.1	20.3
1998	16.1	28.1	20.3	0	1.0	.85	16.8	1.0	15.8	0	28.9	19.3
1999	15.4	28.9	19.3	0	.9	.85	16.1	0.2	15.8	0	29.5	18.4
2000	14.8	29.5	18.4	0	.9	.85	15.3	0	15.3	0	30.0	17.6

[a] These options include the closure of 2 small model mills and 1 large model mill, which is approximately equal to 1.5 thousand metric tons. Net control-caused closures would be equal to 1.5 thousand metric tons minus 1.2 thousand metric tons of premature closure capacity.

[b] Obsolescence rate is .047 of capacity.

[c] Premature closures includes closures caused by control which are assumed to occur in 1983.

[d] Includes new mill capacity additional to new capacity projected for the no closure case (Table B.4).

Table B.11. Production and Inventory Projections - Case N[a]
Low-Growth Industry Demand Scenario
(Thousands of Metric Tons of U_3O_8)

	Demand	Begin. Invent.	Begin. Capacity	New Capacity	Obsolete Capacity[b]	Capacity Utilization Rate	Production			Premature Closure[c]	Ending Inventory	Ending Capacity
							Total	Old	New			
1980	12.5	47.5	18.0	0	.8	.85	14.9	14.9	0	0	49.9	17.2
1981	13.6	49.9	17.2	0	.8	.65	10.8	10.8	0	.3	47.1	16.0
1982	14.9	47.1	16.0	.3	.8	.65	10.2	10.2	0	.3	42.4	15.3
1983	15.2	42.4	15.3	.3	.7	.70	9.1	9.0	0.1	3.9	36.3	10.7
1984	15.8	36.3	10.7	.6	.5	.80	8.5	8.0	0.5	.3	29.0	10.5
1985	16.3	29.0	10.5	1.5[d]	.5	.85	9.3	7.9	1.4	0	22.0	11.5
1986	16.8	22.0	11.5	2.1[d]	.5	.90	11.0	7.9	3.1	0	16.3	13.1
1987	17.1	16.3	13.1	2.1[d]	.6	.90	12.4	7.4	5.0	0	11.6	14.5
1988	16.7	11.6	14.5	2.1[d]	.7	.90	13.7	6.8	6.9	0	8.6	16.0
1989	16.4	8.6	16.0	2.1[d]	.7	.90	15.0	6.2	8.8	0	7.2	17.3
1990	16.3	7.2	17.3	2.1[d]	.8	.90	16.2	5.5	10.7	0	7.0	18.6
1991	16.5	7.0	18.6	1.5	.9	.90	17.0	4.7	12.3	0	7.5	19.2
1992	16.6	7.5	19.2	1.5	.9	.90	17.6	3.9	13.6	0	8.5	19.8
1993	16.7	8.5	19.8	1.5	.9	.85	17.1	2.9	14.2	0	8.9	20.4
1994	16.8	8.9	20.4	1.2[d]	1.0	.85	17.4	2.1	15.3	0	9.5	20.6
1995	16.9	9.5	20.6	1.2[d]	1.0	.85	17.6	1.3	16.3	0	10.2	20.9
1996	16.8	10.2	20.9	1.2[d]	1.0	.85	17.8	0.5	17.3	0	11.3	21.1
1997	16.9	11.3	21.1	.6	1.0	.85	17.7	0	17.7	0	12.1	20.7
1998	16.1	12.1	20.7	0	1.0	.85	17.2	0	17.2	0	13.2	19.7
1999	15.4	13.2	19.7	0	.9	.85	16.4	0	16.4	0	14.1	18.8
2000	14.8	14.1	18.8	0	.9	.85	15.6	0	15.6	0	14.9	17.9

[a] These options include the closure of 5 small model mills, 1 medium mill, and 3 large model mills, which is approximately equal to 4.8 thousand metric tons. Net control-caused closures would be equal to 4.8 thousand metric tons minus 1.2 thousand metric tons of premature closure capacity.

[b] Obsolescence rate is .047 of capacity.

[c] Premature closures includes closures caused by control which are assumed to occur in 1983.

[d] Includes new mill capacity additional to new capacity projected for the no closure case (Table B.4).

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APPENDIX C

ANNUAL INDUSTRY DISPOSAL COSTS, BY ECONOMIC IMPACT CASE AND INDUSTRY CATEGORY, 1980-2000

TABLE C.1

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE A
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	DISCOUNTED TOTAL 10%
1980	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	0.1	0.1	0.1	0.0
1985	0.0	0.0	0.2	0.2	0.1	0.1
1986	0.0	0.0	0.4	0.4	0.3	0.2
1987	0.0	0.0	0.7	0.7	0.5	0.3
1988	0.0	0.0	1.1	1.1	0.7	0.4
1989	0.0	0.0	1.4	1.4	0.9	0.6
1990	0.0	0.0	1.8	1.8	1.1	0.6
1991	0.0	0.0	2.2	2.2	1.2	0.7
1992	0.0	0.0	2.6	2.6	1.4	0.7
1993	0.0	0.0	2.8	2.8	1.4	0.7
1994	0.0	0.0	3.1	3.1	1.5	0.7
1995	0.0	0.0	3.5	3.5	1.6	0.8
1996	0.0	0.0	3.8	3.8	1.7	0.8
1997	0.0	0.0	4.2	4.2	1.8	0.8
1998	0.0	0.0	4.4	4.4	1.8	0.7
1999	0.0	0.0	4.6	4.6	1.7	0.7
2000	0.0	0.0	4.8	4.8	1.7	0.6
CUMULATIVE COST 1980-2000	0.0	0.0	41.7	41.7	19.3	9.6

TABLE C.2

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE B1
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED 5%	TOTAL 10%
1980	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.4	0.4	0.3	0.3
1984	0.0	0.0	1.7	1.7	1.3	1.0
1985	0.0	0.0	4.5	4.5	3.3	2.5
1986	0.0	0.0	9.5	9.5	6.7	4.9
1987	0.0	0.0	16.1	16.1	10.9	7.5
1988	0.0	0.0	24.1	24.1	15.6	10.2
1989	0.0	0.0	32.7	32.7	20.1	12.6
1990	0.0	0.0	41.2	41.2	24.1	14.4
1991	0.0	0.0	49.7	49.7	27.7	15.8
1992	0.0	0.0	58.2	58.2	30.9	16.9
1993	0.0	0.0	63.0	63.0	31.8	16.6
1994	0.0	0.0	71.1	71.1	34.2	17.0
1995	0.0	0.0	79.1	79.1	36.3	17.2
1996	0.0	0.0	87.6	87.6	38.2	17.3
1997	0.0	0.0	96.6	96.6	40.1	17.4
1998	0.0	0.0	101.5	101.5	40.2	16.6
1999	0.0	0.0	105.7	105.7	39.8	15.7
2000	0.0	0.0	109.7	109.7	39.4	14.8
CUMULATIVE COST 1980-2000	0.0	0.0	952.3	952.3	440.8	218.8

TABLE C.3

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE B2
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.5	0.5	0.4	0.3
1984	0.0	0.0	2.2	2.2	1.7	1.4
1985	0.0	0.0	5.8	5.8	4.4	3.3
1986	0.0	0.0	12.4	12.4	8.8	6.3
1987	0.0	0.0	21.0	21.0	14.2	9.8
1988	0.0	0.0	31.5	31.5	20.3	13.4
1989	0.0	0.0	42.7	42.7	26.2	16.5
1990	0.0	0.0	53.8	53.8	31.5	18.9
1991	0.0	0.0	64.9	64.9	36.2	20.7
1992	0.0	0.0	76.1	76.1	40.3	22.0
1993	0.0	0.0	82.4	82.4	41.6	21.7
1994	0.0	0.0	92.9	92.9	44.7	22.2
1995	0.0	0.0	103.4	103.4	47.4	22.5
1996	0.0	0.0	114.5	114.5	50.0	22.7
1997	0.0	0.0	126.2	126.2	52.4	22.7
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	0.0	0.0	1244.3	1244.3	576.0	285.9

TABLE C.4

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE B3
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	1.2	1.2	1.0	0.8
1984	0.0	0.0	5.6	5.6	4.4	3.5
1985	0.0	0.0	14.9	14.9	11.1	8.4
1986	0.0	0.0	31.5	31.5	22.4	16.2
1987	0.0	0.0	53.6	53.6	36.3	25.0
1988	0.0	0.0	80.4	80.4	51.8	34.1
1989	0.0	0.0	108.7	108.7	66.7	41.9
1990	0.0	0.0	137.1	137.1	80.1	48.0
1991	0.0	0.0	165.4	165.4	92.1	52.7
1992	0.0	0.0	193.8	193.8	102.8	56.1
1993	0.0	0.0	209.8	209.8	106.0	55.3
1994	0.0	0.0	236.6	236.6	113.8	56.6
1995	0.0	0.0	263.4	263.4	120.7	57.3
1996	0.0	0.0	291.7	291.7	127.3	57.7
1997	0.0	0.0	321.4	321.4	133.6	57.8
1998	0.0	0.0	337.9	337.9	133.7	55.2
1999	0.0	0.0	351.8	351.8	132.6	52.3
2000	0.0	0.0	365.0	365.0	131.0	49.3
CUMULATIVE COST 1980-2000	0.0	0.0	3169.7	3169.7	1467.3	728.4

TABLE C.5

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE C

BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981.DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	25.9	6.2	0.0	32.1	30.6	29.2
1981	25.9	4.5	0.0	30.4	27.5	25.1
1982	25.9	4.2	0.0	30.1	26.0	22.6
1983	25.9	4.3	0.3	30.5	25.1	20.8
1984	25.9	4.6	1.6	32.0	25.1	19.9
1985	0.0	4.6	4.2	8.8	6.6	5.0
1986	0.0	4.6	8.9	13.5	9.6	6.9
1987	0.0	4.3	15.2	19.5	13.2	9.1
1988	0.0	4.0	22.7	26.8	17.3	11.4
1989	0.0	3.7	30.8	34.5	21.2	13.3
1990	0.0	3.4	38.8	42.1	24.6	14.8
1991	0.0	3.0	46.8	49.8	27.7	15.9
1992	0.0	2.6	54.8	57.4	30.4	16.6
1993	0.0	2.0	59.4	61.3	31.0	16.2
1994	0.0	1.5	66.9	68.5	32.9	16.4
1995	0.0	1.1	74.5	75.6	34.6	16.5
1996	0.0	0.6	82.5	83.1	36.3	16.4
1997	0.0	0.1	90.9	91.0	37.8	16.4
1998	0.0	0.0	95.6	95.6	37.8	15.6
1999	0.0	0.0	99.5	99.5	37.5	14.8
2000	0.0	0.0	103.3	103.3	37.1	14.0
CUMULATIVE COST 1980-2000	129.3	59.3	896.7	1085.3	569.9	336.7

TABLE C.6

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE D
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	25.9	6.2	0.0	32.1	30.6	29.2
1981	25.9	4.5	0.0	30.4	27.5	25.1
1982	25.9	4.2	0.0	30.1	26.0	22.6
1983	25.9	4.3	0.5	30.7	25.2	20.9
1984	25.9	4.6	2.2	32.7	25.6	20.3
1985	0.0	4.6	5.8	10.4	7.8	5.9
1986	0.0	4.6	12.4	17.0	12.1	8.7
1987	0.0	4.3	21.0	25.4	17.2	11.8
1988	0.0	4.0	31.5	35.6	22.9	15.1
1989	0.0	3.7	42.7	46.4	28.5	17.9
1990	0.0	3.4	53.8	57.2	33.4	20.0
1991	0.0	3.0	64.9	67.9	37.8	21.6
1992	0.0	2.6	76.1	78.6	41.7	22.8
1993	0.0	2.0	82.4	84.4	42.6	22.2
1994	0.0	1.5	92.9	94.4	45.4	22.6
1995	0.0	1.1	103.4	104.5	47.9	22.7
1996	0.0	0.6	114.5	115.1	50.2	22.8
1997	0.0	0.1	126.2	126.2	52.5	22.7
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	129.3	59.3	1244.3	1432.9	730.8	416.6

TABLE C.7

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE E
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	30.2	9.7	0.0	40.0	38.0	36.3
1981	30.2	7.0	0.0	37.3	33.8	30.8
1982	30.2	6.6	0.0	36.9	31.8	27.7
1983	30.2	6.7	0.4	37.3	30.7	25.5
1984	30.2	7.2	1.7	39.1	30.6	24.3
1985	0.0	7.2	4.5	11.6	8.7	6.6
1986	0.0	7.2	9.5	16.6	11.8	8.5
1987	0.0	6.8	16.1	22.9	15.5	10.7
1988	0.0	6.3	24.1	30.4	19.6	12.9
1989	0.0	5.8	32.7	38.5	23.6	14.8
1990	0.0	5.2	41.2	46.4	27.1	16.3
1991	0.0	4.6	49.7	54.3	30.3	17.3
1992	0.0	4.0	58.2	62.2	33.0	18.0
1993	0.0	3.1	63.0	66.1	33.4	17.4
1994	0.0	2.4	71.1	73.5	35.4	17.6
1995	0.0	1.7	79.1	80.8	37.0	17.6
1996	0.0	0.9	87.6	88.5	38.6	17.5
1997	0.0	0.1	96.6	96.7	40.2	17.4
1998	0.0	0.0	101.5	101.5	40.2	16.6
1999	0.0	0.0	105.7	105.7	39.8	15.7
2000	0.0	0.0	109.7	109.7	39.4	14.8
CUMULATIVE COST 1980-2000	151.2	92.5	952.3	1196.0	638.6	384.3

TABLE C.8

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE F
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	10%
1980	30.2	9.7	0.0	40.0	38.0	36.3
1981	30.2	7.0	0.0	37.3	33.8	30.8
1982	30.2	6.6	0.0	36.9	31.8	27.7
1983	30.2	6.7	0.5	37.4	30.8	25.6
1984	30.2	7.2	2.1	39.5	30.9	24.5
1985	0.0	7.2	5.5	12.6	9.4	7.1
1986	0.0	7.2	11.6	18.8	13.3	9.6
1987	0.0	6.8	19.7	26.4	17.9	12.3
1988	0.0	6.3	29.5	35.8	23.1	15.2
1989	0.0	5.8	39.9	45.7	28.1	17.6
1990	0.0	5.2	50.4	55.6	32.5	19.5
1991	0.0	4.6	60.8	65.4	36.4	20.8
1992	0.0	4.0	71.2	75.2	39.9	21.8
1993	0.0	3.1	77.1	80.2	40.5	21.1
1994	0.0	2.4	86.9	89.3	43.0	21.4
1995	0.0	1.7	96.8	98.4	45.1	21.4
1996	0.0	0.9	107.1	108.0	47.1	21.4
1997	0.0	0.1	118.1	118.2	49.1	21.3
1998	0.0	0.0	124.1	124.1	49.1	20.3
1999	0.0	0.0	129.2	129.2	48.7	19.2
2000	0.0	0.0	134.1	134.1	48.1	18.1
CUMULATIVE COST 1980-2000	151.2	92.5	1164.3	1408.0	736.7	433.0

TABLE C.9

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE G
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	10%
1980	79.9	16.7	0.0	96.6	92.0	87.8
1981	79.9	12.1	0.0	92.0	83.4	76.0
1982	79.9	11.4	0.0	91.3	78.9	68.6
1983	79.9	11.6	0.5	92.0	75.7	62.8
1984	79.9	12.3	2.2	94.4	74.0	58.6
1985	0.0	12.3	5.8	18.2	13.6	10.3
1986	0.0	12.4	12.4	24.7	17.6	12.7
1987	0.0	11.6	21.0	32.7	22.1	15.2
1988	0.0	10.9	31.5	42.4	27.3	18.0
1989	0.0	10.0	42.7	52.7	32.3	20.3
1990	0.0	9.0	53.8	62.8	36.7	22.0
1991	0.0	8.0	64.9	72.9	40.6	23.2
1992	0.0	6.9	76.1	82.9	44.0	24.0
1993	0.0	5.3	82.4	87.7	44.3	23.1
1994	0.0	4.2	92.9	97.0	46.7	23.2
1995	0.0	2.9	103.4	106.3	48.7	23.1
1996	0.0	1.6	114.5	116.1	50.6	23.0
1997	0.0	0.2	126.2	126.4	52.5	22.7
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	399.5	159.2	1244.3	1803.0	1036.9	676.3

TABLE C.10

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE III
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	50.0	14.0	0.0	63.9	60.9	58.1
1981	50.0	10.1	0.0	60.1	54.5	49.6
1982	50.0	9.5	0.0	59.5	51.4	44.7
1983	50.0	9.7	0.5	60.1	49.4	41.0
1984	50.0	10.3	2.1	62.3	48.8	38.7
1985	0.0	10.3	5.5	15.8	11.8	8.9
1986	0.0	10.3	11.6	21.9	15.6	11.2
1987	0.0	9.7	19.7	29.4	19.9	13.7
1968	0.0	9.1	29.5	38.6	24.9	16.4
1989	0.0	8.3	39.9	48.3	29.6	18.6
1990	0.0	7.5	50.4	57.9	33.8	20.3
1991	0.0	6.7	60.8	67.4	37.5	21.5
1992	0.0	5.7	71.2	76.9	40.8	22.3
1993	0.0	4.5	77.1	81.5	41.2	21.5
1994	0.0	3.5	86.9	90.4	43.5	21.6
1995	0.0	2.4	96.8	99.2	45.4	21.6
1996	0.0	1.3	107.1	108.4	47.3	21.5
1997	0.0	0.2	118.1	118.2	49.1	21.3
1998	0.0	0.0	124.1	124.1	49.1	20.3
1999	0.0	0.0	129.2	129.2	48.7	19.2
2000	0.0	0.0	134.1	134.1	48.1	18.1
CUMULATIVE COST 1980-2000	249.9	133.0	1164.3	1547.2	851.4	530.1

TABLE C.11

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE H2
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	DISCOUNTED TOTAL 10%
1980	50.0	14.0	0.0	63.9	60.9	58.1
1981	50.0	10.1	0.0	60.1	54.5	49.6
1982	50.0	9.5	0.0	59.5	51.4	44.7
1983	50.0	9.7	0.5	60.1	49.5	41.1
1984	50.0	10.3	2.2	62.5	49.0	38.8
1985	0.0	10.3	5.8	16.1	12.0	9.1
1986	0.0	10.3	12.4	22.7	16.1	11.6
1987	0.0	9.7	21.0	30.8	20.8	14.3
1988	0.0	9.1	31.5	40.6	26.2	17.2
1989	0.0	8.3	42.7	51.0	31.3	19.7
1990	0.0	7.5	53.8	61.3	35.9	21.5
1991	0.0	6.7	64.9	71.6	39.9	22.8
1992	0.0	5.7	76.1	81.8	43.4	23.7
1993	0.0	4.5	82.4	86.8	43.9	22.9
1994	0.0	3.5	92.9	96.3	46.3	23.1
1995	0.0	2.4	103.4	105.8	48.5	23.0
1996	0.0	1.3	114.5	115.8	50.5	22.9
1997	0.0	0.2	126.2	126.3	52.5	22.7
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	249.9	133.0	1244.3	1627.2	888.4	548.5

TABLE C.12

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE H3
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	10%
1980	60.5	19.6	0.0	80.1	76.3	72.8
1981	60.5	14.1	0.0	74.7	67.7	61.7
1982	60.5	13.3	0.0	73.9	63.8	55.5
1983	60.5	13.6	0.5	74.6	61.3	50.9
1984	60.5	14.4	2.2	77.2	60.5	47.9
1985	0.0	14.4	5.8	20.3	15.1	11.4
1986	0.0	14.5	12.4	26.8	19.1	13.8
1987	0.0	13.6	21.0	34.7	23.5	16.2
1988	0.0	12.7	31.5	44.2	26.5	18.8
1989	0.0	11.7	42.7	54.4	33.4	21.0
1990	0.0	10.6	53.8	64.4	37.6	22.6
1991	0.0	9.3	64.9	74.3	41.4	23.7
1992	0.0	8.0	76.1	84.1	44.6	24.4
1993	0.0	6.3	82.4	88.6	44.8	23.3
1994	0.0	4.9	92.9	97.7	47.0	23.4
1995	0.0	3.4	103.4	106.8	48.9	23.2
1996	0.0	1.8	114.5	116.3	50.8	23.0
1997	0.0	0.2	126.2	126.4	52.5	22.7
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	302.6	186.4	1244.3	1733.3	972.7	617.8

TABLE C.13

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE #4
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED	TOTAL
					5%	10%
1980	88.0	25.6	0.0	113.6	108.2	103.3
1981	88.0	18.5	0.0	106.5	96.6	88.0
1982	88.0	17.5	0.0	105.4	91.1	79.2
1983	88.0	17.8	0.6	106.3	87.5	72.6
1984	88.0	18.9	2.7	109.6	85.9	68.0
1985	0.0	18.9	7.2	26.1	19.4	14.7
1986	0.0	19.0	15.2	34.1	24.3	17.5
1987	0.0	17.9	25.8	43.6	29.5	20.4
1988	0.0	16.6	38.7	55.3	35.7	23.5
1989	0.0	15.3	52.3	67.6	41.5	26.1
1990	0.0	13.8	66.0	79.8	46.7	28.0
1991	0.0	12.2	79.6	91.9	51.2	29.3
1992	0.0	10.5	93.3	103.8	55.1	30.1
1993	0.0	8.2	101.0	109.2	55.2	28.8
1994	0.0	6.4	113.9	120.3	57.8	28.8
1995	0.0	4.4	126.8	131.2	60.1	28.6
1996	0.0	2.4	140.4	142.8	62.3	28.3
1997	0.0	0.3	154.7	155.0	64.4	27.9
1998	0.0	0.0	162.6	162.6	64.4	26.6
1999	0.0	0.0	169.3	169.3	63.8	25.2
2000	0.0	0.0	175.7	175.7	63.1	23.7
CUMULATIVE COST 1980-2000	439.8	244.2	1525.8	2209.8	1263.5	818.3

TABLE C.14

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE I
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	0.0	68.5	0.0	68.5	65.2	62.2
1981	0.0	49.4	0.0	49.4	44.8	40.9
1982	0.0	46.7	0.0	46.7	40.3	35.1
1983	0.0	47.4	0.5	47.9	39.4	32.7
1984	0.0	50.5	2.2	52.7	41.3	32.7
1985	0.0	50.5	5.8	56.3	42.0	31.8
1986	0.0	50.6	12.4	63.0	44.8	32.3
1987	0.0	47.7	21.0	68.7	46.5	32.0
1988	0.0	44.4	31.5	76.0	49.0	32.2
1989	0.0	40.9	42.7	83.5	51.3	32.2
1990	0.0	36.9	53.8	90.7	53.1	31.8
1991	0.0	32.7	64.9	97.6	54.4	31.1
1992	0.0	28.1	76.1	104.2	55.2	30.2
1993	0.0	21.9	82.4	104.3	52.7	27.5
1994	0.0	17.0	92.9	109.9	52.9	26.3
1995	0.0	11.8	103.4	115.2	52.8	25.1
1996	0.0	6.4	114.5	120.9	52.8	23.9
1997	0.0	0.7	126.2	126.9	52.7	22.8
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	0.0	652.1	1244.3	1896.4	1047.0	644.4

TABLE C.15

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE J
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	25.9	68.5	0.0	94.3	89.8	85.7
1981	25.9	49.4	0.0	75.3	68.3	62.2
1982	25.9	46.7	0.0	72.5	62.7	54.5
1983	25.9	47.4	0.5	73.8	60.7	50.4
1984	25.9	50.5	2.2	78.6	61.6	48.8
1985	0.0	50.5	5.8	56.3	42.0	31.8
1986	0.0	50.6	12.4	63.0	44.8	32.3
1987	0.0	47.7	21.0	68.7	46.5	32.0
1988	0.0	44.4	31.5	76.0	49.0	32.2
1989	0.0	40.9	42.7	83.5	51.3	32.2
1990	0.0	36.9	53.8	90.7	53.1	31.8
1991	0.0	32.7	64.9	97.6	54.4	31.1
1992	0.0	28.1	76.1	104.2	55.2	30.2
1993	0.0	21.9	82.4	104.3	52.7	27.5
1994	0.0	17.0	92.9	109.9	52.9	26.3
1995	0.0	11.8	103.4	115.2	52.8	25.1
1996	0.0	6.4	114.5	120.9	52.8	23.9
1997	0.0	0.7	126.2	126.9	52.7	22.8
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	129.3	652.1	1244.3	2025.7	1158.9	742.4

TABLE C.16

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE K
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	30.2	64.1	0.0	94.3	89.8	85.7
1981	30.2	46.3	0.0	76.5	69.4	63.2
1982	30.2	43.7	0.0	73.9	63.8	55.5
1983	30.2	44.4	0.5	75.1	61.8	51.3
1984	30.2	47.3	2.1	79.6	62.3	49.4
1985	0.0	47.2	5.5	52.7	39.3	29.7
1986	0.0	47.4	11.6	58.9	41.9	30.2
1987	0.0	44.6	19.7	64.3	43.5	30.0
1988	0.0	41.6	29.5	71.1	45.8	30.2
1989	0.0	38.2	39.9	78.2	48.0	30.1
1990	0.0	34.6	50.4	84.9	49.6	29.8
1991	0.0	30.6	60.8	91.3	50.9	29.1
1992	0.0	26.3	71.2	97.5	51.7	28.2
1993	0.0	20.5	77.1	97.6	49.3	25.7
1994	0.0	15.9	86.9	102.8	49.5	24.6
1995	0.0	11.1	96.8	107.8	49.4	23.5
1996	0.0	6.0	107.1	113.1	49.4	22.4
1997	0.0	0.7	118.1	118.8	49.3	21.4
1998	0.0	0.0	124.1	124.1	49.1	20.3
1999	0.0	0.0	129.2	129.2	48.7	19.2
2000	0.0	0.0	134.1	134.1	48.1	18.1
CUMULATIVE COST 1980-2000	151.2	610.2	1164.3	1925.7	1110.6	717.6

TABLE C.17

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE L
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	79.9	68.5	0.0	148.4	141.3	134.9
1981	79.9	49.4	0.0	129.3	117.3	106.9
1982	79.9	46.7	0.0	126.6	109.3	95.1
1983	79.9	46.8	0.5	127.2	104.6	86.9
1984	79.9	49.1	2.2	131.2	102.8	81.5
1985	0.0	49.0	5.8	54.9	41.0	31.0
1986	0.0	49.2	12.4	61.6	43.8	31.6
1987	0.0	46.3	21.0	67.3	45.6	31.4
1988	0.0	43.1	31.5	74.7	48.1	31.7
1989	0.0	39.6	42.7	82.3	50.5	31.7
1990	0.0	35.8	53.8	89.6	52.4	31.4
1991	0.0	31.5	64.9	96.5	53.7	30.7
1992	0.0	27.0	76.1	103.1	54.7	29.9
1993	0.0	20.9	82.4	103.3	52.2	27.2
1994	0.0	16.1	92.9	109.0	52.4	26.1
1995	0.0	11.0	103.4	114.4	52.4	24.9
1996	0.0	5.6	114.5	120.1	52.4	23.8
1997	0.0	0.0	126.1	126.1	52.4	22.7
1998	0.0	0.0	131.9	131.9	52.2	21.6
1999	0.0	0.0	137.4	137.4	51.8	20.4
2000	0.0	0.0	142.6	142.6	51.2	19.3
CUMULATIVE COST 1980-2000	399.5	635.7	1242.0	2277.2	1382.0	940.4

TABLE C.18

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE M1
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	50.0	64.1	0.0	114.0	108.6	103.7
1981	50.0	46.3	0.0	96.2	87.3	79.5
1982	50.0	43.7	0.0	93.6	80.9	70.4
1983	50.0	44.4	0.5	94.8	78.0	64.7
1984	50.0	47.3	2.1	99.3	77.8	61.7
1985	0.0	47.2	5.5	52.7	39.3	29.7
1986	0.0	47.4	11.6	58.9	41.9	30.2
1987	0.0	44.6	19.7	64.3	43.5	30.0
1988	0.0	41.6	29.5	71.1	45.8	30.2
1989	0.0	38.2	39.9	78.2	48.0	30.1
1990	0.0	34.6	50.4	84.9	49.6	29.8
1991	0.0	30.6	60.8	91.3	50.9	29.1
1992	0.0	26.3	71.2	97.5	51.7	28.2
1993	0.0	20.5	77.1	97.6	49.3	25.7
1994	0.0	15.9	86.9	102.8	49.5	24.6
1995	0.0	11.1	96.8	107.8	49.4	23.5
1996	0.0	6.0	107.1	113.1	49.4	22.4
1997	0.0	0.7	118.1	118.8	49.3	21.4
1998	0.0	0.0	124.1	124.1	49.1	20.3
1999	0.0	0.0	129.2	129.2	48.7	19.2
2000	0.0	0.0	134.1	134.1	48.1	18.1
CUMULATIVE COST 1980-2000	249.9	610.2	1164.3	2024.4	1196.1	792.5

TABLE C.19

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE M2
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	50.0	68.5	0.0	118.4	112.8	107.7
1981	50.0	49.4	0.0	99.4	90.2	82.2
1982	50.0	46.7	0.0	96.6	83.5	72.6
1983	50.0	47.4	0.5	97.9	80.5	66.8
1984	50.0	50.5	2.2	102.7	80.5	63.8
1985	0.0	50.5	5.8	56.3	42.0	31.8
1986	0.0	50.6	12.4	63.0	44.8	32.3
1987	0.0	47.7	21.0	68.7	46.5	32.0
1988	0.0	44.4	31.5	76.0	49.0	32.2
1989	0.0	40.9	42.7	83.5	51.3	32.2
1990	0.0	36.9	53.8	90.7	53.1	31.8
1991	0.0	32.7	64.9	97.6	54.4	31.1
1992	0.0	28.1	76.1	104.2	55.2	30.2
1993	0.0	21.9	82.4	104.3	52.7	27.5
1994	0.0	17.0	92.9	109.9	52.9	26.3
1995	0.0	11.8	103.4	115.2	52.8	25.1
1996	0.0	6.4	114.5	120.9	52.8	23.9
1997	0.0	0.7	126.2	126.9	52.7	22.8
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	249.9	652.1	1244.3	2146.3	1263.4	833.9

TABLE C.20

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE M3
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	60.5	68.5	0.0	129.0	122.8	117.2
1981	60.5	49.4	0.0	110.0	99.7	90.9
1982	60.5	46.7	0.0	107.2	92.6	80.5
1983	60.5	47.4	0.5	108.4	89.2	74.0
1984	60.5	50.5	2.2	113.2	88.7	70.3
1985	0.0	50.5	5.8	56.3	42.0	31.8
1986	0.0	50.6	12.4	63.0	44.8	32.3
1987	0.0	47.7	21.0	68.7	46.5	32.0
1988	0.0	44.4	31.5	76.0	49.0	32.2
1989	0.0	40.9	42.7	83.5	51.3	32.2
1990	0.0	36.9	53.8	90.7	53.1	31.8
1991	0.0	32.7	64.9	97.6	54.4	31.1
1992	0.0	28.1	76.1	104.2"	55.2	30.2
1993	0.0	21.9	82.4	104.3	52.7	27.5
1994	0.0	17.0	92.9	109.9	52.9	26.3
1995	0.0	11.8	103.4	115.2	52.8	25.1
1996	0.0	6.4	114.5	120.9	52.8	23.9
1997	0.0	0.7	126.2	126.9	52.7	22.8
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	302.6	652.1	1244.3	2199.0	1309.0	873.8

TABLE C.21

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE M4
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	88.0	83.9	0.0	171.9	163.7	156.3
1981	88.0	60.6	0.0	148.6	134.8	122.8
1982	88.0	57.2	0.0	145.2	125.4	109.1
1983	88.0	57.4	0.6	145.9	120.1	99.7
1984	88.0	60.2	2.7	150.9	118.2	93.7
1985	0.0	60.1	7.2	67.3	50.2	38.0
1986	0.0	60.3	15.2	75.5	53.7	38.7
1987	0.0	56.8	25.8	82.6	55.9	38.5
1988	0.0	52.9	38.7	91.6	59.0	38.8
1989	0.0	48.6	52.3	100.9	62.0	38.9
1990	0.0	43.9	66.0	109.8	64.2	38.5
1991	0.0	38.7	79.6	118.3	65.9	37.7
1992	0.0	33.1	93.3	126.4	67.0	36.6
1993	0.0	25.7	101.0	126.7	64.0	33.4
1994	0.0	19.7	113.9	133.6	64.3	32.0
1995	0.0	13.4	126.8	140.2	64.2	30.5
1996	0.0	6.9	140.4	147.2	64.2	29.1
1997	0.0	0.0	154.7	154.7	64.3	27.8
1998	0.0	0.0	161.7	161.7	64.0	26.4
1999	0.0	0.0	168.4	168.4	63.5	25.0
2000	0.0	0.0	174.8	174.8	62.8	23.6
CUMULATIVE COST 1980-2000	439.8	779.5	1523.1	2742.3	1651.3	1115.2

TABLE C.22

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE N
BASELINE INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	10%
1980	188.5	68.5	0.0	257.0	244.7	233.6
1981	188.5	49.4	0.0	238.0	215.8	196.7
1982	188.5	46.7	0.0	235.2	203.2	176.7
1983	188.5	41.2	0.5	230.2	189.4	157.2
1984	188.5	36.6	3.3	228.4	179.0	141.8
1985	0.0	36.3	9.9	46.2	34.5	26.1
1986	0.0	36.1	19.8	55.9	39.6	28.7
1987	0.0	33.5	30.3	63.8	43.2	29.8
1988	0.0	30.5	42.1	72.6	46.8	30.8
1989	0.0	27.1	54.4	81.5	50.1	31.4
1990	0.0	23.3	66.8	90.1	52.7	31.6
1991	0.0	19.0	78.6	97.6	54.3	31.1
1992	0.0	14.5	89.7	104.1	55.2	30.2
1993	0.0	9.0	95.2	104.2	52.7	27.5
1994	0.0	4.1	105.7	109.9	52.8	26.3
1995	0.0	0.0	115.2	115.2	52.8	25.1
1996	0.0	0.0	120.9	120.9	52.7	23.9
1997	0.0	0.0	126.9	126.9	52.7	22.8
1998	0.0	0.0	132.6	132.6	52.5	21.7
1999	0.0	0.0	138.1	138.1	52.0	20.5
2000	0.0	0.0	143.3	143.3	51.4	19.4
CUMULATIVE COST 1980-2000	942.6	475.8	1373.2	2791.7	1828.3	1332.8

TABLE C.23

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE A
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	0.1	0.1	0.1	0.0
1985	0.0	0.0	0.2	0.2	0.1	0.1
1986	0.0	0.0	0.4	0.4	0.3	0.2
1987	0.0	0.0	0.6	0.6	0.4	0.3
1988	0.0	0.0	0.9	0.9	0.6	0.4
1989	0.0	0.0	1.1	1.1	0.7	0.4
1990	0.0	0.0	1.4	1.4	0.8	0.5
1991	0.0	0.0	1.6	1.6	0.9	0.5
1992	0.0	0.0	1.8	1.8	1.0	0.5
1993	0.0	0.0	1.9	1.9	1.0	0.5
1994	0.0	0.0	2.1	2.1	1.0	0.5
1995	0.0	0.0	2.2	2.2	1.0	0.5
1996	0.0	0.0	2.2	2.2	1.0	0.4
1997	0.0	0.0	2.2	2.2	0.9	0.4
1998	0.0	0.0	2.3	2.3	0.9	0.4
1999	0.0	0.0	2.3	2.3	0.9	0.3
2000	0.0	0.0	2.2	2.2	0.8	0.3
CUMULATIVE COST 1980-2000	0.0	0.0	25.4	25.4	12.2	6.3

TABLE C.24

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE B1
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.4	0.4	0.3	0.3
1984	0.0	0.0	1.7	1.7	1.3	1.0
1985	0.0	0.0	4.5	4.5	3.3	2.5
1986	0.0	0.0	9.0	9.0	6.4	4.6
1987	0.0	0.0	14.2	14.2	9.6	6.6
1988	0.0	0.0	19.9	19.9	12.8	8.4
1989	0.0	0.0	25.6	25.6	15.7	9.9
1990	0.0	0.0	31.2	31.2	18.3	11.0
1991	0.0	0.0	36.5	36.5	20.3	11.6
1992	0.0	0.0	41.2	41.2	21.8	11.9
1993	0.0	0.0	43.4	43.4	21.9	11.4
1994	0.0	0.0	47.4	47.4	22.8	11.3
1995	0.0	0.0	51.0	51.0	23.3	11.1
1996	0.0	0.0	54.5	54.5	23.8	10.8
1997	0.0	0.0	57.2	57.2	23.8	10.3
1998	0.0	0.0	58.1	58.1	23.0	9.5
1999	0.0	0.0	58.1	58.1	21.9	8.6
2000	0.0	0.0	56.4	56.4	20.3	7.6
CUMULATIVE COST 1980-2000	0.0	0.0	610.2	610.2	290.7	148.6

TABLE C.25

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE B2
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	DISCOUNTED TOTAL 10%
1980	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.5	0.5	0.4	0.3
1984	0.0	0.0	2.2	2.2	1.7	1.4
1985	0.0	0.0	5.8	5.8	4.4	3.3
1986	0.0	0.0	11.8	11.8	8.4	6.0
1987	0.0	0.0	18.6	18.6	12.6	8.7
1988	0.0	0.0	26.0	26.0	16.7	11.0
1989	0.0	0.0	33.4	33.4	20.5	12.9
1990	0.0	0.0	40.8	40.8	23.9	14.3
1991	0.0	0.0	47.6	47.6	26.5	15.2
1992	0.0	0.0	53.8	53.8	28.5	15.6
1993	0.0	0.0	56.7	56.7	28.6	14.9
1994	0.0	0.0	61.3	61.3	29.5	14.7
1995	0.0	0.0	64.3	64.3	29.4	14.0
1996	0.0	0.0	65.4	65.4	28.5	12.9
1997	0.0	0.0	66.6	66.6	27.7	12.0
1998	0.0	0.0	67.8	67.8	26.8	11.1
1999	0.0	0.0	67.8	67.8	25.5	10.1
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	0.0	0.0	757.3	757.3	363.7	187.4

TABLE C.26

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE B3
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	1.2	1.2	1.0	0.8
1985	0.0	0.0	5.6	5.6	4.4	3.5
1986	0.0	0.0	14.9	14.9	11.1	8.4
1987	0.0	0.0	29.9	29.9	21.3	15.4
1988	0.0	0.0	47.3	47.3	32.0	22.1
1989	0.0	0.0	66.2	66.2	42.7	28.1
1990	0.0	0.0	85.1	85.1	52.2	32.8
1991	0.0	0.0	104.0	104.0	60.8	36.4
1992	0.0	0.0	121.3	121.3	67.6	38.7
1993	0.0	0.0	137.1	137.1	72.7	39.7
1994	0.0	0.0	144.3	144.3	72.9	38.0
1995	0.0	0.0	156.3	156.3	75.2	37.4
1996	0.0	0.0	163.7	163.7	75.0	35.6
1997	0.0	0.0	166.7	166.7	72.7	33.0
1998	0.0	0.0	169.6	169.6	70.5	30.5
1999	0.0	0.0	172.6	172.6	68.3	28.2
2000	0.0	0.0	172.6	172.6	65.1	25.7
	0.0	0.0	170.7	170.7	61.3	23.1
CUMULATIVE COST 1980-2000	0.0	0.0	1929.1	1929.1	926.6	477.3

TABLE C.27

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE C
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	25.9	6.2	0.0	32.1	30.6	29.2
1981	25.9	4.5	0.0	30.4	27.5	25.1
1982	25.9	4.2	0.0	30.1	26.0	22.6
1983	25.9	4.3	0.3	30.5	25.1	20.8
1984	25.9	4.6	1.6	32.0	25.1	19.9
1985	0.0	4.6	4.2	8.8	6.6	5.0
1986	0.0	4.6	8.5	13.1	9.3	6.7
1987	0.0	4.3	13.4	17.7	12.0	8.3
1988	0.0	4.1	18.7	22.8	14.7	9.7
1989	0.0	3.8	24.1	27.8	17.1	10.7
1990	0.0	3.4	29.4	32.9	19.2	11.5
1991	0.0	3.1	34.3	37.4	20.8	11.9
1992	0.0	2.7	38.8	41.5	22.0	12.0
1993	0.0	2.3	40.8	43.1	21.8	11.3
1994	0.0	1.9	44.2	46.1	22.2	11.0
1995	0.0	1.6	46.3	47.9	21.9	10.4
1996	0.0	1.2	47.1	48.4	21.1	9.6
1997	0.0	0.9	48.0	48.9	20.3	8.8
1998	0.0	0.5	48.8	49.4	19.5	8.1
1999	0.0	0.2	48.8	49.1	18.5	7.3
2000	0.0	0.0	48.3	48.3	17.3	6.5
CUMULATIVE COST 1980-2000	129.3	63.1	545.7	738.1	418.6	266.5

TABLE C.28

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE D

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	25.9	6.2	0.0	32.1	30.6	29.2
1981	25.9	4.5	0.0	30.4	27.5	25.1
1982	25.9	4.2	0.0	30.1	26.0	22.6
1983	25.9	4.3	0.5	30.7	25.2	20.9
1984	25.9	4.6	2.2	32.7	25.6	20.3
1985	0.0	4.6	5.8	10.4	7.8	5.9
1986	0.0	4.6	11.8	16.4	11.6	8.4
1987	0.0	4.3	18.6	22.9	15.5	10.7
1988	0.0	4.1	26.0	30.0	19.4	12.7
1989	0.0	3.8	33.4	37.2	22.8	14.3
1990	0.0	3.4	40.8	44.3	25.9	15.5
1991	0.0	3.1	47.6	50.7	28.2	16.2
1992	0.0	2.7	53.8	56.6	30.0	16.4
1993	0.0	2.3	56.7	58.9	29.8	15.5
1994	0.0	1.9	61.3	63.2	30.4	15.1
1995	0.0	1.6	64.3	65.8	30.1	14.3
1996	0.0	1.2	65.4	66.6	29.1	13.2
1997	0.0	0.9	66.6	67.5	28.0	12.1
1998	0.0	0.5	67.8	68.3	27.0	11.2
1999	0.0	0.2	67.8	68.0	25.6	10.1
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	129.3	63.1	757.3	949.6	520.2	318.8

TABLE C.29

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE E
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	30.2	9.7	0.0	40.0	38.0	36.3
1981	30.2	7.0	0.0	37.3	33.8	30.8
1982	30.2	6.6	0.0	36.9	31.8	27.7
1983	30.2	6.7	0.4	37.3	30.7	25.5
1984	30.2	7.2	1.7	39.1	30.6	24.3
1985	0.0	7.2	4.5	11.6	8.7	6.6
1986	0.0	7.2	9.0	16.2	11.5	8.3
1987	0.0	6.8	14.2	21.0	14.2	9.8
1988	0.0	6.3	19.9	26.2	16.9	11.1
1989	0.0	5.9	25.6	31.4	19.3	12.1
1990	0.0	5.4	31.2	36.6	21.4	12.8
1991	0.0	4.8	36.5	41.3	23.0	13.2
1992	0.0	4.3	41.2	45.5	24.1	13.2
1993	0.0	3.5	43.4	46.9	23.7	12.3
1994	0.0	3.0	46.9	49.9	24.0	12.0
1995	0.0	2.4	49.2	51.6	23.6	11.2
1996	0.0	1.9	50.1	52.0	22.7	10.3
1997	0.0	1.4	51.0	52.3	21.7	9.4
1998	0.0	0.9	51.9	52.7	20.9	8.6
1999	0.0	0.4	51.9	52.2	19.7	7.8
2000	0.0	0.0	51.3	51.3	18.4	6.9
CUMULATIVE COST 1980-2000	151.2	98.4	579.6	829.2	478.8	310.1

TABLE C.30

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE F

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	DISCOUNTED TOTAL 10%
1980	30.2	9.7	0.0	40.0	38.0	36.3
1981	30.2	7.0	0.0	37.3	33.8	30.8
1982	30.2	6.6	0.0	36.9	31.8	27.7
1983	30.2	6.7	0.5	37.4	30.8	25.6
1984	30.2	7.2	2.1	39.5	30.9	24.5
1985	0.0	7.2	5.5	12.6	9.4	7.1
1986	0.0	7.2	11.0	18.2	12.9	9.3
1987	0.0	6.8	17.4	24.1	16.3	11.3
1988	0.0	6.3	24.3	30.6	19.7	13.0
1989	0.0	5.9	31.3	37.1	22.8	14.3
1990	0.0	5.4	38.2	43.6	25.5	15.3
1991	0.0	4.8	44.6	49.4	27.5	15.7
1992	0.0	4.3	50.4	54.6	29.0	15.8
1993	0.0	3.5	53.0	56.5	26.6	14.9
1994	0.0	3.0	57.4	60.4	29.0	14.5
1995	0.0	2.4	60.1	62.6	28.7	13.6
1996	0.0	1.9	61.2	63.1	27.5	12.5
1997	0.0	1.4	62.3	63.7	26.5	11.5
1998	0.0	0.9	63.4	64.3	25.4	10.5
1999	0.0	0.4	63.4	63.8	24.0	9.5
2000	0.0	0.0	62.7	62.7	22.5	8.5
CUMULATIVE COST 1980-2000	151.2	98.4	708.6	958.2	540.7	342.1

TABLE C.31

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE G

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	79.9	16.7	0.0	96.6	92.0	87.8
1981	79.9	12.1	0.0	92.0	83.4	76.0
1982	79.9	11.4	0.0	91.3	78.9	68.6
1983	79.9	11.6	0.5	92.0	75.7	62.8
1984	79.9	12.3	2.2	94.4	74.0	58.6
1985	0.0	12.3	5.8	18.2	13.6	10.3
1986	0.0	12.4	11.8	24.1	17.1	12.4
1987	0.0	11.6	18.6	30.2	20.4	14.1
1988	0.0	10.9	26.0	36.9	23.8	15.6
1989	0.0	10.1	33.4	43.5	26.7	16.8
1990	0.0	9.2	40.8	50.0	29.3	17.5
1991	0.0	8.3	47.6	55.9	31.2	17.8
1992	0.0	7.4	53.8	61.2	32.5	17.7
1993	0.0	6.1	56.7	62.7	31.7	16.5
1994	0.0	5.1	61.3	66.5	32.0	15.9
1995	0.0	4.2	64.3	68.4	31.4	14.9
1996	0.0	3.2	65.4	68.7	30.0	13.6
1997	0.0	2.3	66.6	68.9	28.6	12.4
1998	0.0	1.5	67.8	69.2	27.4	11.3
1999	0.0	0.6	67.8	68.4	25.8	10.2
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	399.5	169.3	757.3	1326.1	829.2	579.9

TABLE C.32

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE H1

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	10%
1980	50.0	14.0	0.0	63.9	60.9	58.1
1981	50.0	10.1	0.0	60.1	54.5	49.6
1982	50.0	9.5	0.0	59.5	51.4	44.7
1983	50.0	9.7	0.5	60.1	49.4	41.0
1984	50.0	10.3	2.1	62.3	48.8	38.7
1985	0.0	10.3	5.5	15.8	11.8	8.9
1986	0.0	10.3	11.0	21.3	15.2	10.9
1987	0.0	9.7	17.4	27.1	18.3	12.6
1988	0.0	9.1	24.3	33.4	21.5	14.2
1989	0.0	8.4	31.3	39.7	24.4	15.3
1990	0.0	7.7	38.2	45.9	26.8	16.1
1991	0.0	6.9	44.6	51.5	28.7	16.4
1992	0.0	6.2	50.4	56.5	30.0	16.4
1993	0.0	5.1	53.0	58.1	29.3	15.3
1994	0.0	4.3	57.4	61.7	29.7	14.8
1995	0.0	3.5	60.1	63.6	29.1	13.8
1996	0.0	2.7	61.2	63.9	27.9	12.6
1997	0.0	2.0	62.3	64.3	26.7	11.6
1998	0.0	1.2	63.4	64.6	25.6	10.6
1999	0.0	0.5	63.4	63.9	24.1	9.5
2000	0.0	0.0	62.7	62.7	22.5	8.5
CUMULATIVE COST 1980-2000	249.9	141.4	708.6	1099.9	656.6	439.7

TABLE C.33

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE H2

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	50.0	14.0	0.0	63.9	60.9	58.1
1981	50.0	10.1	0.0	60.1	54.5	49.6
1982	50.0	9.5	0.0	59.5	51.4	44.7
1983	50.0	9.7	0.5	60.1	49.5	41.1
1984	50.0	10.3	2.2	62.5	49.0	38.8
1985	0.0	10.3	5.8	16.1	12.0	9.1
1986	0.0	10.3	11.8	22.1	15.7	11.3
1987	0.0	9.7	18.6	28.3	19.1	13.2
1988	0.0	9.1	26.0	35.1	22.6	14.9
1989	0.0	8.4	33.4	41.8	25.7	16.1
1990	0.0	7.7	40.8	48.5	28.4	17.0
1991	0.0	6.9	47.6	54.6	30.4	17.4
1992	0.0	6.2	53.8	60.0	31.8	17.4
1993	0.0	5.1	56.7	61.7	31.2	16.3
1994	0.0	4.3	61.3	65.6	31.6	15.7
1995	0.0	3.5	64.3	67.7	31.0	14.7
1996	0.0	2.7	65.4	68.1	29.7	13.5
1997	0.0	2.0	66.6	68.5	28.5	12.3
1998	0.0	1.2	67.8	69.0	27.3	11.3
1999	0.0	0.5	67.8	68.3	25.7	10.1
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	249.9	141.4	757.3	1148.6	680.0	451.7

TABLE C.34

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE H3
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	60.5	19.6	0.0	80.1	76.3	72.8
1981	60.5	14.1	0.0	74.7	67.7	61.7
1982	60.5	13.3	0.0	73.9	63.8	55.5
1983	60.5	13.6	0.5	74.6	61.3	50.9
1984	60.5	14.4	2.2	77.2	60.5	47.9
1985	0.0	14.4	5.8	20.3	15.1	11.4
1986	0.0	14.5	11.8	26.2	18.6	13.5
1987	0.0	13.6	18.6	32.2	21.8	15.0
1988	0.0	12.7	26.0	38.7	25.0	16.4
1989	0.0	11.8	33.4	45.2	27.7	17.4
1990	0.0	10.8	40.8	51.6	30.2	18.1
1991	0.0	9.7	47.6	57.4	31.9	18.3
1992	0.0	8.6	53.8	62.4	33.1	18.1
1993	0.0	7.1	56.7	63.8	32.2	16.8
1994	0.0	6.0	61.3	67.3	32.4	16.1
1995	0.0	4.9	64.3	69.1	31.7	15.0
1996	0.0	3.8	65.4	69.2	30.2	13.7
1997	0.0	2.7	66.6	69.3	26.8	12.5
1998	0.0	1.7	67.8	69.5	27.5	11.4
1999	0.0	0.7	67.8	68.5	25.8	10.2
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	302.6	198.3	757.3	1258.1	765.7	521.8

TABLE C.35

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE H4

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	88.0	25.6	0.0	113.6	108.2	103.3
1981	88.0	18.5	0.0	106.5	96.6	88.0
1982	88.0	17.5	0.0	105.4	91.1	79.2
1983	88.0	17.8	0.6	106.3	87.5	72.6
1984	88.0	18.9	2.7	109.6	85.9	68.0
1985	0.0	18.9	7.2	26.1	19.4	14.7
1986	0.0	19.0	14.4	33.4	23.7	17.1
1987	0.0	17.9	22.8	40.6	27.5	18.9
1988	0.0	16.7	31.9	48.5	31.3	20.6
1989	0.0	15.5	41.0	56.4	34.6	21.7
1990	0.0	14.1	50.1	64.2	37.5	22.5
1991	0.0	12.8	58.4	71.2	39.6	22.7
1992	0.0	11.3	66.0	77.3	41.0	22.4
1993	0.0	9.3	69.5	78.8	39.8	20.7
1994	0.0	7.9	75.9	83.8	40.3	20.1
1995	0.0	6.4	81.7	88.1	40.3	19.2
1996	0.0	4.9	87.4	92.3	40.3	18.3
1997	0.0	3.4	91.7	95.1	39.5	17.1
1998	0.0	2.0	93.1	95.1	37.6	15.5
1999	0.0	0.5	93.1	93.7	35.3	13.9
2000	0.0	0.0	90.4	90.4	32.5	12.2
CUMULATIVE COST 1980-2000	439.8	258.8	977.7	1676.3	1029.5	708.8

TABLE C.36

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE I

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	0.0	68.5	0.0	68.5	65.2	62.2
1981	0.0	49.4	0.0	49.4	44.8	40.9
1982	0.0	46.7	0.0	46.7	40.3	35.1
1983	0.0	47.4	0.5	47.9	39.4	32.7
1984	0.0	50.5	2.2	52.7	41.3	32.7
1985	0.0	50.5	5.8	56.3	42.0	31.8
1986	0.0	50.6	11.8	62.4	44.3	32.0
1987	0.0	47.7	18.6	66.2	44.8	30.9
1988	0.0	44.6	26.0	70.6	45.5	29.9
1989	0.0	41.3	33.4	74.7	45.8	28.8
1990	0.0	37.8	40.8	78.6	45.9	27.5
1991	0.0	34.1	47.6	81.7	45.5	26.0
1992	0.0	30.2	53.8	84.0	44.6	24.3
1993	0.0	24.8	56.7	81.5	41.1	21.5
1994	0.0	21.0	61.3	82.3	39.6	19.7
1995	0.0	17.1	64.3	81.4	37.3	17.7
1996	0.0	13.3	65.4	78.7	34.3	15.6
1997	0.0	9.6	66.6	76.2	31.7	13.7
1998	0.0	6.0	67.8	73.8	29.2	12.1
1999	0.0	2.5	67.8	70.3	26.5	10.4
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	0.0	693.5	757.3	1450.7	853.3	554.6

TABLE C.37

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE J

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	25.9	68.5	0.0	94.3	89.8	85.7
1981	25.9	49.4	0.0	75.3	68.3	62.2
1982	25.9	46.7	0.0	72.5	62.7	54.5
1983	25.9	47.4	0.5	73.8	60.7	50.4
1984	25.9	50.5	2.2	78.6	61.6	48.8
1985	0.0	50.5	5.8	56.3	42.0	31.8
1986	0.0	50.6	11.8	62.4	44.3	32.0
1987	0.0	47.7	18.6	66.2	44.8	30.9
1988	0.0	44.6	26.0	70.6	45.5	29.9
1989	0.0	41.3	33.4	74.7	45.8	28.8
1990	0.0	37.8	40.8	78.6	45.9	27.5
1991	0.0	34.1	47.6	81.7	45.5	26.0
1992	0.0	30.2	53.8	84.0	44.6	24.3
1993	0.0	24.8	56.7	81.5	41.1	21.5
1994	0.0	21.0	61.3	82.3	39.6	19.7
1995	0.0	17.1	64.3	81.4	37.3	17.7
1996	0.0	13.3	65.4	78.7	34.3	15.6
1997	0.0	9.6	66.6	76.2	31.7	13.7
1998	0.0	6.0	67.8	73.8	29.2	12.1
1999	0.0	2.5	67.8	70.3	26.5	10.4
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	129.3	693.5	757.3	1580.0	965.2	652.6

TABLE C.38

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE K

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	10%
1980	30.2	64.1	0.0	94.3	89.8	85.7
1981	30.2	46.3	0.0	76.5	69.4	63.2
1982	30.2	43.7	0.0	73.9	63.8	55.5
1983	30.2	44.4	0.5	75.1	61.8	51.3
1984	30.2	47.3	2.1	79.6	62.3	49.4
1985	0.0	47.2	5.5	52.7	39.3	29.7
1986	0.0	47.4	11.0	58.4	41.5	30.0
1987	0.0	44.6	17.4	62.0	42.0	28.9
1988	0.0	41.7	24.3	66.0	42.6	28.0
1989	0.0	38.6	31.3	69.9	42.9	26.9
1990	0.0	35.3	38.2	73.5	43.0	25.8
1991	0.0	31.9	44.6	76.4	42.6	24.4
1992	0.0	28.3	50.4	78.6	41.7	22.8
1993	0.0	23.2	53.0	76.2	38.5	20.1
1994	0.0	19.6	57.4	77.0	37.1	18.4
1995	0.0	16.0	60.1	76.1	34.9	16.6
1996	0.0	12.4	61.2	73.7	32.1	14.6
1997	0.0	9.0	62.3	71.3	29.6	12.8
1998	0.0	5.6	63.4	69.0	27.3	11.3
1999	0.0	2.4	63.4	65.8	24.8	9.8
2000	0.0	0.0	62.7	62.7	22.5	8.5
CUMULATIVE COST 1980-2000	151.2	648.9	708.6	1508.7	929.4	633.6

TABLE C.39

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE L
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	79.9	68.5	0.0	148.4	141.3	134.9
1981	79.9	49.4	0.0	129.3	117.3	106.9
1982	79.9	46.7	0.0	126.6	109.3	95.1
1983	79.9	46.8	0.5	127.2	104.6	86.9
1984	79.9	49.1	2.2	131.2	102.8	81.5
1985	0.0	49.0	5.8	54.9	41.0	31.0
1986	0.0	49.2	11.8	60.9	43.3	31.3
1987	0.0	46.3	18.6	64.9	43.9	30.3
1988	0.0	43.3	26.0	69.3	44.6	29.4
1989	0.0	40.0	33.4	73.4	45.1	28.3
1990	0.0	36.6	40.8	77.4	45.3	27.1
1991	0.0	32.9	47.6	80.6	44.9	25.7
1992	0.0	29.2	53.8	83.0	44.0	24.0
1993	0.0	23.8	56.7	80.5	40.7	21.2
1994	0.0	20.1	61.9	82.0	39.4	19.6
1995	0.0	16.2	66.6	82.8	37.9	18.0
1996	0.0	12.3	69.5	81.8	35.7	16.2
1997	0.0	8.5	71.3	79.7	33.1	14.3
1998	0.0	4.7	72.4	77.2	30.5	12.6
1999	0.0	1.1	72.4	73.5	27.7	10.9
2000	0.0	0.0	70.1	70.1	25.2	9.5
CUMULATIVE COST 1980-2000	399.5	673.8	781.4	1854.6	1197.7	854.6

TABLE C.40

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE M1

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	50.0	64.1	0.0	114.0	108.6	103.7
1981	50.0	46.3	0.0	96.2	87.3	79.5
1982	50.0	43.7	0.0	93.6	80.9	70.4
1983	50.0	44.4	0.5	94.8	78.0	64.7
1984	50.0	47.3	2.1	99.3	77.6	61.7
1985	0.0	47.2	5.5	52.7	39.3	29.7
1986	0.0	47.4	11.0	58.4	41.5	30.0
1987	0.0	44.6	17.4	62.0	42.0	28.9
1988	0.0	41.7	24.3	66.0	42.6	28.0
1989	0.0	38.6	31.3	69.9	42.9	26.9
1990	0.0	35.3	38.2	73.5	43.0	25.8
1991	0.0	31.9	44.6	76.4	42.6	24.4
1992	0.0	28.3	50.4	78.6	41.7	22.8
1993	0.0	23.2	53.0	76.2	38.5	20.1
1994	0.0	19.6	57.4	77.0	37.1	18.4
1995	0.0	16.0	60.1	76.1	34.9	16.6
1996	0.0	12.4	61.2	73.7	32.1	14.6
1997	0.0	9.0	62.3	71.3	29.6	12.8
1998	0.0	5.6	63.4	69.0	27.3	11.3
1999	0.0	2.4	63.4	65.8	24.8	9.8
2000	0.0	0.0	62.7	62.7	22.5	8.5
CUMULATIVE COST 1980-2000	249.9	648.9	708.6	1607.4	1014.9	708.4

TABLE C.41

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE M2

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	50.0	68.5	0.0	118.4	112.8	107.7
1981	50.0	49.4	0.0	99.4	90.2	82.2
1982	50.0	46.7	0.0	96.6	83.5	72.6
1983	50.0	47.4	0.5	97.9	80.5	66.8
1984	50.0	50.5	2.2	102.7	80.5	63.8
1985	0.0	50.5	5.8	56.3	42.0	31.8
1986	0.0	50.6	11.8	62.4	44.3	32.0
1987	0.0	47.7	18.6	66.2	44.8	30.9
1988	0.0	44.6	26.0	70.6	45.5	29.9
1989	0.0	41.3	33.4	74.7	45.8	28.8
1990	0.0	37.8	40.8	78.6	45.9	27.5
1991	0.0	34.1	47.6	81.7	45.5	26.0
1992	0.0	30.2	53.8	84.0	44.6	24.3
1993	0.0	24.8	56.7	81.5	41.1	21.5
1994	0.0	21.0	61.3	82.3	39.6	19.7
1995	0.0	17.1	64.3	81.4	37.3	17.7
1996	0.0	13.3	65.4	78.7	34.3	15.6
1997	0.0	9.6	66.6	76.2	31.7	13.7
1998	0.0	6.0	67.8	73.8	29.2	12.1
1999	0.0	2.5	67.8	70.3	26.5	10.4
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	249.9	693.5	757.3	1700.6	1069.7	744.1

TABLE C.42

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE M3
LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	DISCOUNTED TOTAL 10%
1980	60.5	68.5	0.0	129.0	122.8	117.2
1981	60.5	49.4	0.0	110.0	99.7	90.9
1982	60.5	46.7	0.0	107.2	92.6	80.5
1983	60.5	47.4	0.5	108.4	89.2	74.0
1984	60.5	50.5	2.2	113.2	88.7	70.3
1985	0.0	50.5	5.8	56.3	42.0	31.8
1986	0.0	50.6	11.8	62.4	44.3	32.0
1987	0.0	47.7	18.6	66.2	44.8	30.9
1988	0.0	44.6	26.0	70.6	45.5	29.9
1989	0.0	41.3	33.4	74.7	45.8	28.8
1990	0.0	37.8	40.8	78.6	45.9	27.5
1991	0.0	34.1	47.6	81.7	45.5	26.0
1992	0.0	30.2	53.8	84.0	44.6	24.3
1993	0.0	24.8	56.7	81.5	41.1	21.5
1994	0.0	21.0	61.3	82.3	39.6	19.7
1995	0.0	17.1	64.3	81.4	37.3	17.7
1996	0.0	13.3	65.4	78.7	34.3	15.6
1997	0.0	9.6	66.6	76.2	31.7	13.7
1998	0.0	6.0	67.8	73.8	29.2	12.1
1999	0.0	2.5	67.8	70.3	26.5	10.4
2000	0.0	0.0	67.0	67.0	24.0	9.1
CUMULATIVE COST 1980-2000	302.6	693.5	757.3	1753.3	1115.3	784.0

TABLE C.43

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE M4

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL 5%	10%
1980	88.0	83.9	0.0	171.9	163.7	156.3
1981	88.0	60.6	0.0	148.6	134.8	122.8
1982	88.0	57.2	0.0	145.2	125.4	109.1
1983	88.0	57.4	0.6	145.9	120.1	99.7
1984	88.0	60.2	2.7	150.9	118.2	93.7
1985	0.0	60.1	7.2	67.3	50.2	38.0
1986	0.0	60.3	14.4	74.7	53.1	38.4
1987	0.0	56.8	22.8	79.6	53.9	37.1
1988	0.0	53.1	31.9	84.9	54.7	36.0
1989	0.0	49.1	41.0	90.0	55.3	34.7
1990	0.0	44.9	50.1	94.9	55.5	33.3
1991	0.0	40.4	58.4	98.8	55.0	31.5
1992	0.0	35.7	66.0	101.7	54.0	29.5
1993	0.0	29.2	69.5	98.7	49.9	26.0
1994	0.0	24.6	75.9	100.5	48.4	24.1
1995	0.0	19.9	81.7	101.5	46.5	22.1
1996	0.0	15.1	85.2	100.3	43.8	19.9
1997	0.0	10.4	87.4	97.8	40.6	17.6
1998	0.0	5.8	88.8	94.6	37.4	15.5
1999	0.0	1.3	88.8	90.2	34.0	13.4
2000	0.0	0.0	85.9	85.9	30.8	11.6
CUMULATIVE COST 1980-2000	439.8	826.2	958.2	2224.1	1425.3	1010.0

TABLE C.44

ANNUAL FLOWS OF INDUSTRY DISPOSAL COSTS, CASE N

LOW GROWTH INDUSTRY DEMAND SCENARIO
(MILLIONS OF 1981 DOLLARS)

	EXISTING TAILINGS	FUTURE TAILINGS EXISTING MILLS	FUTURE TAILINGS NEW MILLS	TOTAL COST	DISCOUNTED TOTAL	
					5%	10%
1980	188.5	68.5	0.0	257.0	244.7	233.6
1981	188.5	49.4	0,0	238.0	215.8	196.7
1982	188.5	46.7	0.0	235.2	203.2	176.7
1983	188.5	41.2	0.5	230.2	189.4	157.2
1984	188.5	36.6	2.2	227.3	178.1	141.1
1985	0.0	36.4	6.4	42.8	31.9	24.2
1986	0.0	36.4	14.2	50.6	36.0	26.0
1987	0.0	34.0	22.9	56.9	38.5	26.5
1988	0.0	31.3	31.5	62.9	40.5	26.7
1989	0.0	28.4	40.2	68.6	42.1	26.4
1990	0.0	25.1	48.9	74.0	43.3	25.9
1991	0.0	21.7	56.3	78.0	43.4	24.8
1992	0.0	18.0	62.5	80.5	42.7	23.3
1993	0.0	13.4	64.8	78.3	39.5	20.6
1994	0.0	9.8	70.1	79.9	38.4	19.1
1995	0.0	6.0	74.8	80.8	37.0	17.6
1996	0.0	2.2	79.4	81.6	35.6	16.2
1997	0.0	0.0	81.3	81.3	33.8	14.6
1998	0.0	0.0	78.7	78.7	31.1	12.9
1999	0.0	0.0	75.0	75.0	28.3	11.1
2000	0.0	0.0	71.4	71.4	25.6	9.7
CUMULATIVE COST 1980-2000	942.6	505.0	881.1	2328.7	1619.0	1230.9

APPENDIX D

REGULATORY FLEXIBILITY ACT CERTIFICATION

Appendix D

Regulatory Flexibility Act Certification

The proposed standards for uranium mill tailings at active sites will not have a significant impact on a substantial number of small entities. The basis for this finding is that of the 27 licensed uranium mills, only one qualifies as a small entity, and this mill will not be impacted by the standards. Almost all the mills are owned by large corporations. Table D.1 lists each of the mills, the operating company, the parent corporation of the operator, and the employment of the parent corporation.

Based on the Small Business Administration's generic small entity definition of 500 employees, four of the parent corporations could qualify as small businesses. However, for the reasons explained below, we have determined that three of the mills owned by these companies are not small entities, while the fourth will not be affected by the standards.

American Nuclear Corporation - This company is a small business based on the SBA generic definition since it has only 125 employees. American Nuclear is a partner with Federal Resources Corporation, a company with 600 employees, in the ownership of the uranium mill in Gas Hills, Wyoming. According to the Regulatory Flexibility Act, a small business is one which is independently owned and operated. Since this mill is not independently owned by a small business, it is not a small entity.

Reserve Oil and Minerals Corporation - This company is a small business since it only has a handful of employees. However, since it is a partner with the Standard Oil Company of Ohio in the Seboyeta, New Mexico, mill, the mill is not a small entity.

Energy Fuels Nuclear - This privately-held company has 450 employees and owns about 60 percent of the Blanding, Utah, uranium mill. Two Swiss utilities own the remaining interest in the mill (Engineering and Mining Journal, November 1978, p. 125). Since the mill is not independently owned, it is not a small entity.

Bokum Resources Corporation - This company is in a state of bankruptcy, and only a skeleton staff of employees exists. They are currently in litigation with a utility which has contributed to the bankruptcy. Since the mill at Marquez, New Mexico, has never operated and has no plans to operate for several years, there are no mill tailings and, therefore, no control costs to be incurred by this company. Therefore, the proposed standards will have no impact on this company.

Table D.1. Ownership of Licensed Uranium Mills

Uranium Mill Location	Mill Operator	Parent Corporation	Employment of Parent Corporation (Thousands)
Canon City, CO	Cotter Corp.	Commonwealth Edison	16
Uravan, CO	Union Carbide Corp.	Union Carbide Corp.	101
Seboyeta, NM	Sohio-Reserve	The Standard Oil Co. (Ohio)	23
		Reserve Oil & Minerals Corp.	< 1
Church Rock, NM	United Nuclear Corp.	UNC Resources, Inc.	5
Bluewater, NM	Anaconda	Atlantic Richfield Co.	53
Ambrosia Lake, NM	Kerr-McGee Nuclear Corp.	Kerr-McGee Corp.	11
Milan, NM	Homestake Mining Co.	Homestake Mining Co.	2
Marquez, NM	Bokum Resources Corp.	Bokum Resources Corp.	< 1
Edgemont, SD	Tennessee Valley Authority	U.S. Government	--
Panna Maria, TX	Chevron	Standard Oil of California	40
Falls City, TX	Conoco-Pioneer	Conoco, Inc.(a)	42
		Pioneer Corp.	3
Ray Point, TX	Exxon Corp.	Exxon Corp.	177
Blanding, UT	Energy Fuels Nuclear	Energy Fuels Nuclear(b)	< 1
La Sal, UT	Rio Algom Ltd.	Rio Algom Ltd.	7
Moab, UT	Atlas Corp.	Atlas Corp.	2
Hanksville, UT	Plateau Resources, Ltd.	Consumers Power Co.	12
Ford, WA	Dawn Mining Co.	Newmont Mining Corp.	12
Wellpinit, WA	Western Nuclear	Phelps Dodge Corp.	15
Gas Hills, WY	Federal-American Partners	Federal Resources Corp.	< 1
		American Nuclear Corp.	< 1
Gas Hills, WY	Pathfinder Mines Corp.	General Electric(c)	402
Powder River, WY	Rocky Mountain Energy/ Mono Power	Union Pacific Corp.	33
		Southern California Edison Co.	14
Powder River, WY	Exxon Corp.	Exxon Corp.	177
Jeffrey City, WY	Western Nuclear Corp.	Phelps Dodge Corp.	15
Gas Hills, WY	Union Carbide Corp.	Union Carbide Corp.	101
Shirley Basin, WY	Pathfinder Mines Corp.	General Electric(c)	402
Shirley Basin, WY	Petrotomics Co.	Getty Oil Co.	17
Red Desert, WY	Minerals Exploration Co.	Union Oil Co.	17

(a) Conoco and Dupont merged in 1981.

(b) The Blanding mill is owned 60 percent by Energy Fuels Nuclear, and the remainder is owned by two Swiss utilities.

(c) General Electric has sold 80 percent of its interest in their uranium mills to the French Company, Cogema.